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OF

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AND OF THEIR

INVENTORS & IMPROVERS,

BY

Robert Stuart Esqre

Civil Engineer.

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HISTORICAL AND DESCRIPTIVE ANECDOTES OF STEAM-ENGINES, AND OF THEIR INVENTORS AND IMPROVERS:

BY
ROBERT STUART,
CIVIL ENGINEER.

TH' INVENTION ALL ADMIRED; AND EACH HOW HE
TO BE TH' INVENTOR MISSED; SO EASY IT SEEMED
ONCE FOUND, WHICH YET UNFOUND, MOST WOULD HAVE THOUGHT
IMPOSSIBLE. *Milton.*

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CONTENTS.

INTRODUCTION,

CHAPTER I.

Honours paid to early inventors, 4. Statue of Memnon, 5. Kircher's Commentaries, *note*, 6. Hero of Alexandria, 8. Editions of Spiritalia, *note*, 9. Hero's steam-toys, 11. William of Malmsbury—Gerbert's clock, 15. Alberti, 16. Astrologers, 17. Cardan's æolipile, *note*—Mathesius—Whirling æolipile, 20. Besson, 21. Ramelli—Baptista Porta 24. Wilkins quoted, *note*—Solomon De Caus raising water—Giovanni Branca, 29. Cornelius Drebbel, 33. Bishop Wilkins, *memoir*, 34. Heating buildings by steam, 35. Kircher the Jesuit raising water by steam, 36. Jack of Hilton, 38. Tail-piece *Kircher's steam-engine.*

CHAPTER II.

Lord Herbert captures Monmouth—Imprisoned in Dublin—Letter to his wife, *note*, 42. Returns from exile, and imprisoned in Tower—Letter to Colonel Copeley, *note*, 44. Some of his contrivances at Ragland, *note*, 45. Dedicates his Century of Inventions to Parliament, 47. Lord Orford quoted, *note*, 48. First steam-engine, 49. Editions of the Century of Inventions, *note*, 52. Inventions of the Earl of Worcester, *note*, 54. Describes high-pressure-engine, 56. Exact and true definition of his water-work, *note*, 57. Two designs for his engine de-

a 2

scribed, 60, 61. Act of Parliament, 62. His prayer, 63. Inscription found on his coffin—Marchioness of Worcester, 64. Letter of a priest to her, 65. Cosmo of Medicis, 66. Describes Lord Worcester's engine at Vauxhall, 68. Jean Hautefeuille's gunpowder engine—Duchess of Orleans—De Sourdis—Huyghens, 70. Sir Samuel Morland memoir, *note*—Machine for raising water, 73. Hutton quoted, *note*, 74. Manuscript of experiments on steam, 75. Table of cylinders, 76. Anonymous author describes a steam-engine, 77.

CHAPTER III.

Doctor Papin's mode of softening bones by steam, 83. Describes safety-valve, 84. Mode of estimating strength of steam, 86. Quantity of coals and effect produced, 87. Machine for raising water, 88. Air-pump, 90. Transmits motion by it, 91. Vacuum by condensing vapour of gunpowder, 91. Describes engine producing vacuum by condensation of steam, 92. Observes waste of fuel from imperfect combustion—Suggests reversing the flame, 95. Hints at steam-guns and steam-boats, 96. Authors who have mentioned wheel-boats, *note*, 97. Prince Rupert's wheel-boat, 98. Tail-piece, *wheel-boat*, described by Valturius.

CHAPTER IV.

Captain Thomas Savery, 101. Notices of his life—His wheel-boat objected to by Dummer, *note*, 103. Sir I. Newton mentions Savery, 106. De Samaurez' stream measurer, 107. Savery's first engine, 109. Editions of Miner's Friend, *note*, 110. Advantages of fire-engine, 112. Its uses, 115. Directions for erecting it—Action of the apparatus, 118. Desagulier's account—Robison's, Stuart's, and Switzer's commentaries on it, *note*, 122. Allen's notice of Savery, *note*, 124. Hooke designs a steam-engine, *note*, 125. Peculiarities of Savery's machine, 126. Amonton's, 128. His fire-wheel, 130. Papin resumes his experiments, 132. Elector of Hesse, 133. Elector Charles's engine, 135.

CHAPTER V.

Biographical Notices of Thomas Newcomen and John Cawley, 144. First atmospheric engine, 146. Introduction of safety-valve by Desaguliers, *note*, 148. Switzer's account of Newcomen's invention, *note*, 150. Sniffing clack, 153. Newcomen's boiler, 155. Griff engine, 156. Condensing by injection, 157. Bradley, 158. Engine for Mr. Balle, 159, Hum-

phry Potter invents scoggan—derivation of the word, *note*, 160. Biographical notice of Desaguliers, 161. S. Gravesend and Desaguliers' experiment—Steelyard safety-valve introduced, *note*, 162. Four-way-cock and injection in the inside of receivers applied to Savery's engine, 163. Engines sent to St. Petersburg—Accident by bursting, 164.

Chapter VI.

Beighton invents hand gear, 171. Its action described, 172. Engine described by Desaguliers, 173. Potter's mechanism for opening cocks, 174. Engine with a buoy described, 175. Two other forms of engine described, 178, 179.

Chapter VII.

Biographical notice of Leupold—Improves Amonton's fire-wheel, 184. Improves Savery's engine, 185. Invents high-pressure-lever engine, 187. Beighton calculates a table of proportions of parts—Meyand, Meyer, and Bosfraud's engines, 189.

Chapter VIII.

Doctor Allen's experiments, 195. Modes of boiling water, *note*, 196. Allen suggests to force a current of air upon fuel, 197, and to navigate a ship by pumping water from its stern with a steam-engine—Wheel-boats, *note*, 198. Gensanne's engine, 199. Jonathan Hulls invents a steam-boat, 200. Payne's method of expanding fluids, 202. Blake, 203. De Moura's engine—Bernoulli and Gautier, 204. Keane Fitzgerald's experiments to increase steam, 205. His apparatus for converting an alternate into a rotary motion—Brindley's improvements, 207. Biographical notice of Cugnot—He invents steam-carriages, 209. Blakey's engine, 210. Anecdotes of Smeaton, 212.

Chapter IX.

Biographical notices of James Watt—and of his family, *note*, 218. Biographical notice of Dr. Robison, *note*—He suggests an idea of a steam carriage to Watt, 221. Watt's first experiment, 222. Memoir of Professor Anderson, *note*—Watt repairs model of Newcomen's engine, 223. Tries some experiments upon it—Brindley's wooden cylinders, *note*, 225. Smeaton's experiments, *note*, 226. Watt's experiment on heating water by steam, 228.

CHAPTER X.

Watt invents the condenser and stuffing box, and excludes atmospheric pressure from the piston—Surrounds cylinder with a non-conducting casing—Invents air-pump, 234. Gainsborough's claim, *note*, 235. Watt's model described, 236. His second experiment, 238.

CHAPTER XI.

Biographical notice of Dr. Roebuck, *note*, 244. Erects Carron iron woks, 246. Works coal mines at Kinniel, 247. Watt's experiments at Kinneil, 248. Watt gets a patent for his invention, 249. Describes a high-pressure-engine, and a rotary engine, 250. Observes expansion of steam in a vacuum, 251. Embarrassments of Roebuck, 252.

CHAPTER XII.

Roebuck, and Bolton, and Watt compared—Roebuck sells his interest in patent to Bolton, 257. Difficulties Watt had to contend with, 260. Leaves Scotland—Soho, 261. First experimental engine erected at Soho, 263. Places a barometer on condenser, 267. Introduces steam between the cylinder and its casing, 269. Improvement on piston—Applies to Parliament to prolong term of his patent, 270. Public experiments at Soho, 272. Bolton's estimate of power, 273. Watt invents counter, 275.

CHAPTER XIII.

Clarke and Stuart's rotary motion given up—Genevois' steam-boat and duckfoot oars—Boat moved by gunpowder, *note*, 281. Biographical notice of Comte d'Auxiron, *note*, 282. His steam-boat—Biographical notice of MM. Periers, *note*, 283. Their steam-boat—Marquis Ducrest's account of it, 284. Perrier procures a steam-engine from Bolton and Watt, 285. Fails in his water-company project—Dr. Falck proposes two cylinders, 286.

CHAPTER XIV.

Premium paid to Watt and Bolton—Smeaton's experiments on atmospheric engine, 292. Constructs a small one at Austhorpe, 293. Chacewater engine, 295. Regulating motion of engine 297. Cataract, 298. Float in pipe, 299. Warning guage, 300. Boiler whistle, 301. Water guage—Brass used

in many parts of the apparatus—Spelter, 302. Boring cylinder, 303. Cast-iron improved, and used for cylinders and axes, 304. Cast-iron, thin copper, and plate-iron, used for boilers—Boiler built of stone, *note*, 305. Carron cylinders, 306. Wilkinson invents boring machine, 307.

CHAPTER XV.

Bolton's success in systematizing labour, 312. Condenser applied to Newcomen's engine—First form of condenser, 313. Condensing by injection—Number of condenser pumps used, 314. Cylinder improved—Piston made to rise in vacuo, 317. Found defective—Watt's mode of introducing improvements, 318. Expansive engine, 319. Expansion of steam used as a regulator of velocity, 323. Contrivances to equalize motion, 324.

CHAPTER XVI.

Biographical notice of Matthew Wasbrough, 329. Describes a rotular movement—Pickard introduces a crank and loaded wheel, 330. Wasbrough introduces it into some woollen manufactories—Biographical notice of John Taylor, *note*, 331. Wasbrough employed by government, 333. Commissioners of navy deceive him, 335. His death noticed, *note*, 336. Smeaton's opinion of condensing engine, 337. Watt says Pickard's contrivance was stolen from him, 339. Used in many engines long before this period, 340.

CHAPTER XVII.

Watt invents a steam-wheel—Semi-rotary engine, 344. Second rotary engine, 345. Invents double impulse engine, 347. Watt converts alternating into a rotary movement, 348. Applies fly-wheel as a regulator—Invents parallel motion, 349. Conjectures as to its originating from Suardis' pen, 348. Invents sun and planet wheel motion, 353. Bettancourt visits London, 354. Inspects Albion Mills, 355. Prony's misstatement, 356.

CHAPTER XVIII.

Method of regulating speed of millstones by governor, 360. Applied by Clarke of Manchester to throttle valve—Watt describes a steam-carriage, 361. Marquis de Joufroy's steamboat, 362. Hornblowers double cylinder engine, 363. Wilson offers to bet against its performance, 365. Hornblowers fail in

their attempts to introduce their machines—Watt's improved hand-gear, 366. Spanner weights—Single impulse engine described—Contrivance to prevent accidents by the descent of the piston, 370. Joints of steam-engines, 371. Indicator supersedes barometer guage, 373. Double impulse engine described, 374. Boiler and its regulating appendages, 376. Biographical notice of John Smeaton, *note*, 378. Watt's fire-place, 380. Cameron's steam-engine, 381.

CHAPTER XIX.

Moving a vessel by a steam-engine proposed by Henry and Paine, 385. Fitch and Rumsey's steam-boats, 386. Rush's letter to Lettsom, 387. Thornton's letter to Lettsom, 388. Rumsey and Fitch are both unsuccessful—Oliver Evan's uses high pressure steam—Latrobe's report, *note*, 389. Miller of Dalswinton, 391. Symington constructs a model of a steam-boat for him, 363.

CHAPTER XX.

Cooke's steam-wheel, 399. Bramah's hydraulic press, 400. Biographical notice of him, 401. His rotary steam-engines, 404. Symington's engine, 405. François engine, 407. Kempel's engine, 408. Sadler's engine, 409. Thomson's engine, 410. Rumsey's steam-boat on the Thames, 411. Memoir of the Earl of Stanhope, 412. His steam-boat, 413. Fulton proposes a steam-boat plan to him—Chancellor Livingstone's steam-boat on Hudson, 415. Cartwright's steam wheel, 416. His condensing engine, 417. Biographical notices of him, *note*, 418. Invents metallic packing, 422. Sadler's reciprocating engine, 423. Murray's Improvement on the boiler, 425. Murdoch's steam-wheel—Bishop's steam-wheel, 426. Nuncarrow's engine, 427. Hornblower's steam-wheel, 428.

CHAPTER XXI.

Watt's patent contested, 434. Bramah's letter to the Judge, 435. On the patent laws, *note*, 436. Watt retires from business, 438. Slow progress in introducing his mechanism, 439. Number of engines in London, Manchester, and Leeds, 440. Crowther's engine—and Cartwright's engines—Murray's air-pump, 442. Bramah's fourway cock, 444. Roberton's engine—Symington's narrative, 445. Is patronised by Lord Dundas, 446. Steam-boat on Forth and Clyde Canal, 447. Fulton visits Symington, 448.

CHAPTER XXII.

Trevithic and Vivian invent high pressure steam-engine, 455. Danger of their apparatus imaginary, 458. Their steam-carriage, 459. Travel it on a rail-road, 460. Oliver Evans' high pressure engine, 461. Strength of his boilers, *note*, 462. His steam œlipile, *note*, 463. His steam-wheel, *note*, 464. His volcanic steam-engine, *note*, 465. Stevens disputes his invention, 466. Constructs a steam-boat—Evans moves a carriage by steam, and launching it also sails it by a steam-engine, 467. Hornblower's rotary engine, 469. Wilcox's projects—Woolfe's improvement on Hornblower's engine, 470. Rider's scheme for boring, 471. Boaz's engine, 472. Trotter's steam-wheel—Flint's steam-wheel, 473. Wilcox's engines, 474.

CHAPTER XXIII.

Biographical notice of Fulton, 477. His book on canals, *note*. 478. Announces a mode of destroying ships—it is rejected by the French minister, 479. And by the Dutch Directory—Bonaparte enables him to try it, 480. Failure in Brest harbour—Discarded by Bonaparte, 481. Receives hints of a steam-boat from Dr. Cartwright—Establishes panoramas at Paris, 482. Makes experiments on steam-boats at Plombieres—M. De Blanc's steam-boat, 483. Fulton's experiment on the Seine—Blasco de Garay, *note*, 485. Fulton comes to England—Fails in his experiment at Deal, 487. Returns to New York, and succeeds in perfecting his steam-boat, 488. Her first voyage, 489. His patent invaded, 491. Compared with Oliver Evans, 492. Writes to Henry Bell, 493. Linaker's boat, 494.

CHAPTER XXIV.

Steam-wheel tried at Soho, 500. Maudslay's engine, 502. Mead's steam-wheel—Clegg's steam-wheel, 503. Notices of Bolton, 506. Watt's character of him, 509. His death—Chapman's steam-wheel, 510. Witty's rotary engines, 511. Onion's steam-wheel, 512.

CHAPTER XXV.

M. Uvillé comes to England—Boase's memoir—Uvillé buys Travithic's model, 516. Tries it in Mexico, 517. Comes to England, 516. Trevithic makes engines for Peru, 518. Trevithic arrives at Lima, 519. Trevithic improves his engine, 520.

CHAPTER XXVI.

Henry Bell receives a letter from Fulton—Begins to construct a steam-boat, 524. Report on steam-boats—Dawson constructs a steam-boat—Opposition of Watermen to their introduction, 525. Bell fails in his speculation, 526. Robertson Buchanan, memoir of, 527. His steam-boat, 528. Fulton's steam-frigate—Pendulum boat, *note*, 530. Wright's boat—Experiment at Glasgow—Steam-frigate launched—Fulton's death, 531. His character, *note*, 532. Dodd's voyage, 534. Ralph Dodd and George Dodd, memoirs of, *note*, 535.

CHAPTER XXVII.

Biographical notices of James Watt, 544. Memoir of W. Playfair, *note*, 547. Death of Watt, 550. Character of, by Jefrey, 551. Turner's steam-wheel, 553. Routledge, 554. Malam's steam-wheel—Moore's steam-wheel, 555. Congreve's steam-wheel—Pontifex's improvement on Savery's engine, 556. Masterman's steam-wheel, 557. Perkins' boiler—Brunel's engine, 560. Vaughan's atmospheric engine—Alban's generator, 561. Stuart's Practical Treatise on Construction, 562.

CHAPTER XXVIII.

Watt Club, *note*, 565. The King's donation, 566. Lord Liverpool's character of Watt—Dupin's statement, *note*, 567. Turner's answer, 568. Sir Humphry Davy's speech—Mr. Bolton, 569. Mr. Huskisson, 570. Sir James Mackintosh, 571. Mr. Brougham, 573. Mr. Littleton—Mr. Peel, 574. Mr. Wilberforce, 575. Meeting at Glasgow, 576. Grants to patentees, 577. Steam-boats on the Clyde, 579. Henry Bell's case, 580.

CHAPTER XXIX.

Street's vapour-engine, 585. Rivaz's engine, 586. Cecil's gas-engine, 587. Brown's gas-engine, 593.

CHAPTER XXX.

Faraday's experiments, 597. Brunel's compressed gas-engine, 598. Barton's pistons—Howard's alcohol-engine, 599. Foreman's steam-wheel, 600. Perkins' steam-guns, 601.

Jonathan Hornblower's rockets, 603. Perkins' experiments, 604. Woisard's engine—Morey's engine, 607. Montgery's turpentine engine—Galvanic engine, 608. Hodgkins's engine, 609.

CHAPTER XXXI.

List of patents for inventions and improvements in steam-engines—and in the economy and management of fuel, 609 to Index.

LIST (

Inde.

Porta,

Worce

Worc

Papi

Sav

Sav

Sav

Sa

A

H

LIST OF ENGRAVINGS OF MACHINES.

		Page
HERO.	Three steam toys . . . *opposite*	13
PORTA, KIRCHER, DE CAUS.	Engines of Branca, steam-wheel	32
WORCESTER.	Engine without a piston, from Description in Century of Inventions	60
WORCESTER II.	Engine with a piston . . .	62
PAPIN.	1, Safety-valve. 2, Mode of raising a piston by steam. 3, Ground plan. 4, Changing a reciprocating to a circular motion	92
SAVERY I.	Model exhibited before the Royal Society .	109
SAVERY II.	Elevation of his improved engine .	117
SAVERY III.	Parts of same	118
SAVERY.	Side of same machine	120
AMONTON.	Fire-wheel	130
HESSE.	Elevation and section of Papin's machine .	135
NEWCOMEN A.	Elevation of his first apparatus . .	
NEWCOMEN B.	Elevation of improved machine .	158
SAVERY M.	Elevation of Bradley's engine . .	159

		Page
BEIGHTON.	Hand-gear as improved by him . .	171
NEWCOMEN F.	Desaguliers' view of Newcomen's engine	173
NEWCOMEN.	Mechanism on a German engine . .	174
NEWCOMEN 1725.	View of an engine working with a buoy	175
NEWCOMEN D.	View of another variety of the atmospheric engine	178
NEWCOMEN E.	Another variation	179
LEUPOLD H.	Leupold's improvement of Amonton's fire-wheel	184
LEUPOLD III.	His arrangement of Savery's apparatus	185
LEUPOLD.	First high pressure lever engine . .	188
GENSANNE	. . . .	199
HULLS.	First steam-boat	201
BLAKEY.	Improvement on Savery's engine . .	210
WATT L.	Watt's models	256
WATT XO.	Arrangement of his first engines . .	263
SMEATON.	Fig. 1, Elevation of Smeaton's hand-gear. Fig. 2, Horizontal section of the same. Fig. 3, Bottom of cylinder. Fig. 4, steam-valve . .	296
WATT N.	Sections of cylinder	317
WATT O.	Contrivance to equalise motion . . .	328
WATT P.	Contrivances to equalise motion . .	230
WATT Q.	Watt's steam-wheel, fig. 2. Section of his semi-rotary engine, figs. 1, 3, and 4 . . .	344
WATT R.	Watt's rotary-engine	345
WATT R.	Engraving referred to with this mark in page 347, is marked	
WATT K.	. . .	
WATT D.	Valves of reciprocating engine and great lever beam	348
WATT B.	Parallel motion	352
WATT C.	Sun and planet wheels	358
WATT I.	Engine governor	360

Page

HORNBLOWER—WATT. Hornblower's double cylinders, fig. 1. Watt's piston plunger, fig. 2. Valve treddle weights, fig. 3. Boiler, fig. 4. Indicator, fig. 5. 363

WATT. SINGLE IMPULSE ENGINE 367

WATT. DOUBLE IMPULSE ENGINE 374

BRAMAH. Cooke's steam-wheel. Sadler's steam-wheel, fig. 1. Bramah's steam-wheel, figs. 3 and 4. Bramah's steam wheels, fig. 5. François scheme, fig. 6. Thompson's modification of Newcomen's cylinder 402

CARTWRIGHT. Single engine 417

SADLER. Condensing engine 423

MURDOCH, HORNBLOWER, MURRAY, &c. Fig. 1, Murdoch's steam-wheels. Fig. 2, Murray's valves. Figs. 3, 4, 5, Hornblower's steam-wheel. Fig. 6, Cartwright's steam-wheel. Fig. 7, Roberton's cylinder. Fig. 8, Murray's air-pump . . . 426

NUNCARROW'S ENGINE 427

MURRAY. Elevation of Murray's condensing engine . 443

MURRAY. Section of the same 444

MURRAY D. Ground plan of same 444

TREVITHIC AND VIVIAN. Elevation of their high pressure engine 455

EVANS. Fig. 1, Section of Oliver Evans' high pressure engine. Fig. 2, Boaz's mercury engine. Figs. 3 and 4, Flint's steam-wheel. Fig. 5, Hornblower's. Fig. 6, Trotter's steam-wheel. Fig. 7. Wilcox's wheel 461

SOHO, CLEGG, MEAD. Figs. 1, 2, 3, 4, Clegg's steam-wheel. Figs. 5, 6, Mead's steam-wheel. Fig. 7, Soho wheel 500

CHAPMAN, WITTY, ONIONS. Fig. 1, Chapman's steam-wheel. Figs. 2, 3, 4, 5, Witty's rotary engines. Fig. 6, Onion's steam-wheel 510

TURNER, ROUTLEDGE, RIDER, ALBAN. Fig. 1, Routledge's steam-wheel. Figs. 2, 3, Turner's steam-wheel. Fig. 4, Rider's steam-wheel. Fig. 5, Alban's boiler 554

Page

MOORE, MASTERMAN, PERKINS. Fig. 1, Moore's steam-wheel. Figs. 2, 3, 4, 5, Masterman's steam-wheel. Fig. 6, Perkins' boiler . . . 587

CECIL'S Gas-engine 589

BROWN'S Gas-engine 592

HOWARD, FOREMAN, BRUNEL, EVE. Fig. 1, Howard's Alcohol engine. Fig. 2, Foreman's steam-wheel. Fig. 3, Brunel's compressed gas-engine. Figs. 4, 5, Eve's steam-wheels 596

LIST OF PORTRAITS.

	Page
Hieronymus Cardan	18
Joachim Mathesius	20
Baptista Porta	24
Dr. John Wilkins	34
Athanasius Kircher	36
Marquis of Worcester	48
Sir Samuel Morland	74
Captain Savery	103
Charles, Elector of Hesse	139
Dr. T. Desaguliers	161
Mr. Jonathan Hulls	203
Mr. J. Brindley	207
Mr. John Smeaton	212
Mr. James Watt	216
Mr. Matthew Boulton	256
Mr. Matthew Wasbrough	331

	Page
Mr. J. C. Hornblower	365
Earl of Stanhope	413
Dr. Cartwright	430
Mr. Robert Fulton	478
Mr. Ralph Dodd	534
Mr. Thomas Masterman	556
Mr. M. I. Brunel	569
Mr. Samuel Brown	594
Mr. Jacob Perkins	601
Mr. Thomas Hodgskin	610

LIST OF FAC SIMILES OF AUTOGRAPHS.

Page

I. The Marquis of Worcester—part of original Manuscript of the Century of Inventions. 2. Sir Hugh Platte. 3. Mr. J. Hartlib . *opposite* 50

II. Sir Samuel Morland. 2. Charles II. . . 72

III. Sir Isaac Newton. 2. Doctor Robert Hooke. 3. William III. 106

IV. Prince William, Landgrave of Hesse Cassel. 2. Liebnitz. 3. Doctor Denys Papin . . 133

V. Mr. Henry Beighton. 2. Professor Richard Bradley. 3. Doctor J. T. Desaguliers. 4. Doctor Stephen Hales. 5. Mr. John Smeaton 164

VI. Mr. John Payne. 2. Sir Martin Triewald. 3. Mr. Keane Fitzgerald 202

Page

VII. Mr. James Watt. 2. Mr. Matthew Boulton. 3. Mr. Jabez Carter Hornblower. 4. Mr. Matthew Wasbrough 334

VIII. Mr. Marc Isambard Brunel. 2. Mr. Jacob Perkins. 3. Mr. R. Witty. 4. Sir William Congreve. 5. Mr. Samuel Clegg. 6. Mr. J. Boaz. 7. Captain Walter Foreman . . 607

INTRODUCTION.

SOME years ago, the ten thousand steam-engines, which then were reckoned to be in Great Britain, were estimated to perform daily the labour of more than two hundred thousand horses—equal to the power of twelve hundred thousand men expending their energy to the greatest mechanical advantage. But, as machines require neither rest, nor relaxation, and can operate without impairing their power during those portions of time usually assigned for a cessation of animal labour, these ten thousand engines could develop from sunrise to sunrise a power superior to that of four and a half millions of labourers; an effect greater than the entire manual labour of England: yet, notwithstanding the importance of the power they developed to the national manufactures, and the display of mechanical ingenuity exhibited in the construction of the machines themselves, they were

unknown but by name to the great bulk even of that portion of the community engaged in manufacturing processes. Two works only, devoted to a popular account of the principles of mechanical philosophy, contained a few brief notices of their general principles, and attempted to give an explanation of two of the methods by which they were applied. A third work gave a tolerable account of another of the numerous modifications of the apparatus, and an expensive Cyclopedia had arranged some observations on a few of its more recent changes; but, until the appearance of these anecdotes, no attempt to give a detailed history of the progress of improvements on steam-engines generally, and of their inventors and improvers, had been made in this or any other language.

This extraordinary indifference appears to have arisen from the operation of the remains of some ancient prejudices, biassing public feeling with regard to the cast of mind necessary for the production of mechanical inventions. Even that philosopher whose discoveries have been described as links connecting the mind of man with the spirit of God, is called by Dean Swift, "that fellow Newton over the way, a glass grinder, and a maker of spectacles." The sublime conceptions of the author of the "Principia" were considered by the copper-farthing Dean to be but common applications of vulgar mechanic skill*.

* The "proud Venetians" were less fastidious than Dean Swift. "The two Italians," says Howel, in a letter to Sir Robert Mansel, "who are the bearers hereof, by report here, are the best *gentlemen workmen* that ever blew crystal. One is allied to Antonio Miotti, the other is cousin to Maralao. I was, since I came hither (Venice), in Murano, a little island where crystal glass is made, and 'tis a rare sight to see a

But, on reflection it will be found, that mechanical invention differs nothing from that which gives value to those pursuits, considered to be more mental and refined. Homer and his Iliad,

whole street, where on the one side there are twenty furnaces at work. They say here, that although one should transplant a glass-furnace from Murano to Venice herself, or to any of the little assembly of islands about her, or to any other part of the earth besides, and use the same materials, the same workmen, the same fuel, the self-same ingredients every way, yet they cannot make crystal glass in that perfection for beauty and lustre as in Murano. Some impute it to the quality of the circumambient air that hangs over the place, which is purified and attenuated by the concurrence of so many fires that are in those furnaces night and day perpetually, for they are like the vestal fire which never goes out. The art of glass-making is here very highly valued; for whosoever be of that profession are *gentlemen ipse facto*, and it is not without reason, it being a rare kind of knowledge and chemistry to transmute dust and sand, to such a diaphanous dainty body, as you see a crystal glass is. They have a saying here, that the first handsome woman, that ever was made, was made of Venice glass, which implies beauty, but brittleness withal, and Venice is not unfurnished with some of that mould, for no place abounds more with lasses and glasses."

A mechanic, cotemporary with the Dean exclaims, "But alas! with shame be it spoken, what treatment have men of the best genius met with in England but contempt and scorn; every ignorant blockhead, without ever considering the profit or value of an invention, throws up his nose, and cries he is for no projects. Solomon sent the sluggard to the ant to learn wisdom, it is a great scandal as well as a pity that Christians should be sent to the Turks to learn goodnature and generosity, as well as morality and common honesty. At Grand Cairo in Egypt, they have such a profound respect to new inventions, that whoever is the discoverer of any new art or invention is immediately clad in cloth of gold, and carried in triumph throughout the whole city, with trumpets and other musical instruments playing before him, and presented to every shop to receive the joyful acclamations and generous presents of his fellow citizens. Leo, the geographer, witnessed one of these displays or solemnities as he calls them—the performance lauded was only *a flea chained* to a sheet of white paper."

Virgil and his Æneid, Milton and his Paradise Lost, were minds and productions of the same exquisite fibre and tension with Savery and Watt with their engines, Huyghens with his watch, Arkwright with his spinning frame, Meikle with his threshing machine, and Bramah with his hydraulic press. In fact all observation shows, that the power of combining machines and constructing poems, in the "heroic or any other line," are usually united in the same individual! that all poets are mechanical inventors, and all mechanical inventors are poets. Hooke made verses as well as machines; and when he presented thirty-seven different projects for flying, had his attention been directed to express his thoughts in metre, he had previously shown a facility for describing the glories of his mistress's eye-brows in as many sonnets. Lord Worcester also made verses; and his "Century of Inventions" has been commented upon by more than one person, as if it were a poem, although not written in rhyme. Sir Samuel Morland indited love-songs, and sang them to his theorbo. When total blindness had fallen on the jovial old man, he buried the manuscript of the effusions of his younger muse, considering them to be "gay deceits,"—and betook himself, in his ninetieth year, to the composition of psalms. Arkwright was famed among his customers for a light hand and an exquisite edge, and for verses which cut as keen as his razors. Watt, in his youth, was a rhymester, and few men of his generation read more fairy tales and poetry—even in the meridian of his life, and in the busiest period of his employment, the greater portion of his time was devoted to indulgence in this mental luxury. Few who knew the excellent Rennie near the close

of his life, would have dreamt of finding under his inflexible man of business exterior, an enthusiastic admirer of poetry and music; or, that in his youth he chaunted his own lyrics, which were distinguished for their spirit and taste. His contemporary, the venerable Telford, when building rough stone fence walls as a journeyman mason, was an esteemed contributor to the poetical corner of the Scots' Magazine—and his productions were embued with much of the pastoral sweetness and pathos of those of the Bard of Ayr. Sir William Congreve let off many poetical squibs before he exploded his rockets. Sir Christopher Wren is complimented by a bishop on his poetical acquirements: "You have," says the Right Reverend Father in God, "admirably well hit his genius: your verse is harmonious, your philosophy very instructing for life, your liberty in translating enough to make it seem to be an English original, and yet not so much but that the mind of the author is still religiously preserved." Could more be said of the paraphrases of Dryden or Pope? One of the ablest disciples of Sir Humphry Davy hazarded the opinion, that some of the ex-president's speculations "graduated into the poetry of science." The devotee was ignorant of his idol's early propensities, and he knew not that Sir Humphry wooed the Muses before he experimented on the gases, and produced, "in the heroic measure," his address to St. Michael's Mount, long before he invented his safety-lamp. Dr. Cartwright early distinguished himself for his poetical compositions; but the fine taste, and exalted feeling, which pervade them, must yield to the exquisite invention and extensive usefulness of his power-loom.

If it were easy to show that all celebrated mechanical inventors were gifted with the faculty of poets, it were as easy to prove that all poets of name have been gifted with mechanical propensities; many of their most admired passages are accounts of machines. "Milton's hell-gates move on more than mortal hinges, and his war-chariots may yet form a subject for illustration in a mechanical college. The horse of Epeus has lately been adduced as an early locomotive! and Homer's description of cars shows that he had an eye for beauty in carts which could have carried them to perfection *." In Persia itself, where the very frame and structure of society is anti-mechanical,

* "The whole tribe of dramatic geniuses are in possession of telescopes for distinguishing spirits, and trumpets by which a person may disclose to another at a distance, his intention to put his companion to death, in Stentorian sounds, and yet be unknown to the object of his vengeance, in whose ear it may be thundered. A harper is said to have wheedled stones to forget their gravity, and playing them into the proper 'figure,' he ceased his music, and the dancers long remained in the good set order of ashlar work, forming the walls of Thebes. The Greek was a clever fellow, but not more so than a Father Tournemine, who lived in Paris at the beginning of the eighteenth century. This worthy ecclesiastic attempted the construction of a machine, by which persons should enjoy the pleasure of good eating and drinking without being at the expense or trouble of procuring or preparing food. By turning a winch, a man or woman could allay the cravings of hunger as well as by a meal of the most substantial viands. The Father anticipated being able to adapt his invention to please all customers, from they who dined on rump steaks, plum-pudding, and ale, to made-dish gourmands of every degree. Like those physicians who administer bread pills to fanciful patients, the worthy Father made his machine, in similar cases, produce some tunes; but this music had no effect whatever in persuading the gastric juice to spare the coats of those stomachs whose master or mistress did not ply the crank-handle."—*Young's Essay on Imagination*, p. 36.

we have a remarkable instance of the union of poetic and mechanic power: Futteh Alee Khan, the Shah ul Shaer, or Malec ul Shaer, poet laureate of the kingdom, is descended from an ancient family for many successive generations governors of Cashan. He possesses great wit, a brilliant imagination, a fine taste and a correct judgment; his poems are ranked, by his countrymen, as next in merit to the admired strains of their charming Ferdousi. Nor is the fertility of his genius less: for already, exclusive of minor pieces, he has spun one hundred and fifty thousand couplets. This wholesale stanza manufacturer has found time to construct several complicated pieces of *machinery of his own invention;* among these are spinning-jennies, paper-mills, and steam-engines, and when the gifted Persian was recently visited by an English traveller, he was found busily engaged in the construction of a printing-press. The ingenuity of Scarron received its direction from the gallantry of the age in which he lived. Then the fair sex was the dominant half of the body politic as well as of the body domestic, and Scarron was pre-eminently a ladies'-man, in a community which bowed the knee to beauty. Nature, however, in one of her caprices, had denied him the power of using his limbs; most distressing of all was the physical inability of his hands to approach "his dome of thought, the palace of his soul." But the amiable little monster invented a machine for taking off his hat. And like De Renzy in our own time, who with only one arm, aided by a fine mechanical invention, performs with such ease all the courtesies of a gentleman, that it is doubtful if the man-of-fashion air could be heightened were some angel to restore the

limb which lays on the field of a victorious battle. So Scarron even drew applause for his courtier-like salute—and that personal defect which would have ruined the reputation of a less mechanical genius, added an indescribable charm to the graces of his chivalric attentions. Drummond of Hawthornden—the classic, romantic, and tender Drummond—excelled in mechanics, and employed himself in restoring ancient, and discovering original contrivances of naval, military, and civil utility. Pope was mechanical in every thing; and Kirke White and Bloomfield were no mean practitioners—and if Campbell and Scott, and Moore and Southey, have not run the gauntlet of the patent-office; and if Brunel, and Cecil, and Trevithic have not bestridden Pegasus—to use an algebraic phrase, the equation may be resolved, merely by changing their signs and transposing them.

Poets as well as mechanics differ in the manner in which they exhibit their conceptions. One excels in loftiness of thought, another in delicacy of perception; a third pleases by his harmonious numbers, and a fourth is esteemed for the useful tendency of his writings. Some mechanics delight in clockwork, others in steam-engines—the machines of others are polished even to a bolt-head—and a ponderous mass, whose jerking motion is the nuisance of a district, constructed by one whose ear is more refined than his rival manufacturers, moves with all the softness of a watch; and another applies the principles of a toy to a machine for abridging labour. There are rhymesters who will spin a fine thought through an infinity of words; there are also artist wire-drawers, who by great skill will draw an ounce or two of

gold into a thread which will encircle the world. Your sounding, flashy, sparkling authors of a thousand brilliant nothings, are a sort of kaleidoscope artists, whose most bizarre, original, regular, and harmonious combinations are produced by a thread of rag, a pin's head, a leaf, a bead, or a bit of crystal.

A few poets have been persons of condition, but a skill in combination (they call it the inspiration of the muse) has been "the claim sufficient" for the greater number, though low born, and of a mean habit of life assuming a station of social as well as moral dignity, and researches into their history have, therefore, not been considered unbecoming, or derogatory, either to the man of learning, or to the historian. Can that curiosity which is laudable with regard to this class of artists be less praiseworthy when it seeks gratification in a knowledge of the personal incidents of a similar class, whose labours confer, not only more durable fame on communities than the boasted songs of the bards, but more permanent power than the enactments of the legislator, or the exploits of the warrior.

The promulgator of a law, or the leader of an army, are not, however, remembered merely as individuals who prescribed a duty, or defined a right, or acquired, or rescued a principality;—they are held up to admiration for the effects which flowed from their wisdom or prowess,—as a father of his country, the conservator of its honour, or the assertor of its power. Yet it has never happened that the memory of inventors is associated with a sense of the benefits which communities have derived from their inventions. They are recollected merely as persons who constructed

this or that ingenious machine—*one* of which forms as it were a kind of back ground to the mental effigy; and here ends the recollection both of the talent of the discoverer, and the value of his performance.

There does not appear, however, to be any good reason why results should be excluded from our estimate of one man's genius, and yet that we should make these form the great merit of another's labours. To take an example—The population of the world is stated at about 906 millions of souls; and a man of experience has calculated that 400 thousand persons in the cotton, woollen, and iron trades produce as much yarn, cloth, and metal ware as 200 millions of men could do with the implements used about seventy years ago. If we further consider that of every four persons in existence, three are women, children, aged persons, and idlers, the machines in action in Great Britain spin more yarn, fabricate more cloth, and mould and polish more metal ware, than could be spun, fabricated, and moulded, by all the labourers at this moment in existence if they used hand implements. Compare then the invention of those engines with the acquisition of kingdoms, what Alexander, or Cæsar, or Tamerlane ever founded so great an empire as this, which was created in one generation by two ignorant weavers (both of whom died in miserable poverty,) a fustian manufacturer, a mathematical instrument maker, a physician, a country clergyman, and a blacksmith; all persons so humble in station and modest in their pretensions, that an author who was lately *thrown upon* a notice of some incidents in the life of one of the best known, though not the greatest of the seven, thought it due to the fastidiousness of public

taste to claim indulgence for diverging into so obscure and tasteless a path of biographical research —Even he, in a laboured apology, never dreamt of attributing the overflow of national wealth which all ascribe to the extension of our manufactures to the humble artists whose genius produced the machines which alone gave us the superiority over all other nations. This deference to refinement might, therefore, perhaps have been better omitted; our regret is, that of those who widely extended the dominion of mind over matter, little should be known beyond the fact, that while their country was reaping unknown benefits from their inventions, it left their authors to pine in obscurity and want; one of the two, who fortunately were *partial* exceptions, when he appealed for protection against piracy to that law, which apparently secured to him the fruits of his ingenuity, found it to have been enacted on the principle of an "order of the day," issued by a Bajazet to discourage and repress individual exertion. "If the enterprise succeeds," said the caliph, "let the booty be equally divided among my whole army—if its success be doubtful, and the leader survives, let him lose his head."

They who dissent from what they are pleased to designate as the overweening conceit of inventors have remarked, that even their most boasted productions when narrowly examined do not appear to exhibit any great ingenuity; but on the contrary, many of them are such simple and obvious things as to preclude the notion of invention altogether. These critics, however, confound ingenuity with complexity, and are persons who would think Swift's puddle to be amazingly deep because they could not distinguish the bottom of it. The simplicity which they despise

is, of itself, a proof of the most exquisite art, and it is a curious circumstance in the history of inventions, that the most complicated forms are those which have first presented themselves to the eye of the artist. The very machine which prints this page affords a beautiful illustration of the fact. By Applegarth and Cowper's improvement on Konig's press, forty wheels were discarded from the mechanism—now he is a bold man who would say, that getting rid of these forty wheels was not as great a proof of contrivance as the first placing them there; and in the sister art of poetry he who expresses a noble thought in ten or a dozen words, is certainly as great a genius as he who may have the knack of diffusing it through a thousand.

Many volumes have been written on the gradual refinements of language, and learned men have pointed out the immense stride in improvement which has arisen from an unimportant innovation, yet millions had spoken the imperfect language without dreaming of the simple means by which the finishing touches could be given to it. The effects also which have flowed from apparently the most simple contrivances are almost incredible; and should those who are familiar with their most perfect forms be but casual observers, they may be startled at the exaggerated terms in which their value may be estimated—or disgusted with the claims of some mechanic who, by merely adding a wheel or pulley, or giving a trifling difference to their proportions, may, by these means, have been the first to make the machine efficient. The simple process of drawing a cork will furnish the necessary illustrations.

The inventor of bottles is unknown; but these

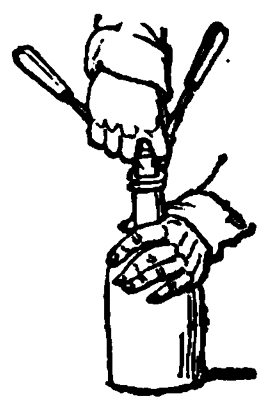
were in use for centuries before corks were thought of, and these again were employed for generations before a convenient method was hit upon for their extraction. The exhilarating contents could then only be tasted by what is now

technically called "beheading the bottle." More expert practitioners had many opportunities of showing their skill in removing the impediment by a dexterous twist of the fingers; or if that

were impracticable, teeth were called in as their natural auxiliaries: here, however, in many cases it was doubtful, whether the cork would follow the teeth, or the teeth remain in the cork; and if an

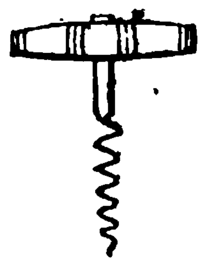
obstinate remnant would remain, a *nail* was a ready means of dislodging the stubborn plug, particle by particle,—when at any time, through

an impatience of the nibbling labour, or a despair of accomplishing a clean extraction at all, it was resolved at once to send the obstacle the wrong way; this was then, indeed, an invaluable instrument. A pair of skewers, or forks, inserted "witchwise,"



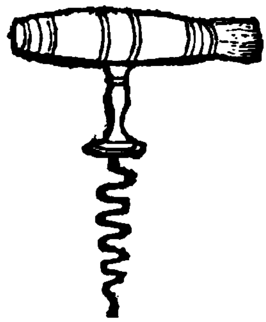
would sometimes accomplish those difficult cases which had baffled the exertions of all the naturals. Twisting the lower extremity of the "bare bodkin" into a spiral form, and adding a handle to it, was the thought of a master genius; and in

this shape mankind, for ages, were contented to avail themselves of its services—and even at the present hour, some barbarous, uncouth countries and districts may be named where it is still the extractor in most general use. In our civilized



land, it must be yet in the recollection of many, that this was, in numerous cases, a very inefficient machine; and the pleasure of beholding the generous beverage, beaming through a crust of many years, was cruelly damped by the experience, that in proportion to the pains taken in fixing the cork, was the mental agony which must be endured during all attempts to remove it. Jovial fellows, who forget those days, in their moments of inspiration, may talk indeed of their Phillises, their Ianthes, their Delias, their Saccharissas, their Chloes, and their what nots,—let them henceforth mingle a little gratitude with their admiration, and glorify a nymph greater than them all. Miss O'Rourke, like her own exquisite potteen punch, was a delightful compound from ingredients, both mental and corporeal, of the most opposite nature. The friend of Kosciusko, and the authoress of the Rhapsody, which afterwards rung so often throughout the country to the favourite tune (Gramachree) of the patriot Pole,—such another hostess was not in England wide, and no other of

her order ever conferred so great a benefit on bottle-suckers as she did, by her superlative invention of placing a *button* at the end of the screw-worm.



Henceforth the decantering process was a mere matter of routine. When, in her green old age, Death laid his hand on the inventress—a piratical screwmaker also took to himself the credit and profit of the button addendum. Yet Miss O'Rourke shall never be forgotten, even although her master-piece, some few years later, was eclipsed

and may be yet superseded by the *King's Screw*,

which can receive no addition either to its beauty or convenience, except it be probably some little steam appendage to make it self-acting. These are trifling additions to a simple instrument *, yet

* A shoemaker's AWL is a very simple instrument, much simpler than a corkscrew, but even an awl has had its stages of improvement. "The first awls were *plain conical punches*, that made a round hole in the leather. It was, however, soon discovered that this form was erroneous, for the hole thus made was never more than half filled with the two waxed threads crossing each other. Indeed, the section of the two threads might be regarded as two circles which touched one another, and were enclosed in a third circle which touched both the others at the opposite extremities of their diameters. Now geometry teaches us that those two small circles are only half the surface of the larger enclosing circle.

"The conical awl was then *flattened*, and had an oval form as to its section given it—and, some time afterwards, the awl was filed so as to give it *four faces*, the section being a lozenge with cutting edges—but still the awl was straight. Although this straightness is useful in many cases, yet it was improper in the business of shoemaking.

"Suppose it were wished to sew together quite close to the edge two pieces of leather placed one upon the other, and that a straight awl is used; the hole that it will make will constantly push out the leather towards the edge, and give it a convex form, and when the sewing is done the edge will exhibit a row of festoons, which it will be necessary to rub down by means of a knife in order to give a regular edge to the pieces; but which, by this means, will lose much of its strength. Now, if on the contrary a crooked awl is used, and pushed in properly, it may be brought very near the edge, by making it describe the arc of a circle, whose convexity is opposite to the edge—by this simple means the festooned appearance of the edge produced by the straight awl will not be formed, and of course the strength of the leather will be preserved undiminished, and the sewing itself will be strong. Unfortunately the name of the person who conceived the happy idea of *bending the awl* is lost."

"However little we reflect upon the manner in which the hole ought to be made in the two pieces of leather, which are placed one upon the other, we shall be convinced that the awl should come out of the lower piece, at the same distance

they produced a great revolution in its use and value. Equally simple improvements have produced still more wonderful effects in machines of more elaborate construction—and above all other mechanisms which can be named, on the steam-engine.

In detailing these, the fastidious feeling which looks only upon the more perfect form of any production has found no place; simple matters, it is hoped, have not been estimated as being unimportant because they are simple, if at the *time* of their introduction they either produced or gave rise to an improvement in the mechanism. In other cases, where the claims urged by the inventors themselves have somewhat overstepped the limits of a fair valuation, their high pretensions have been softened with a strong leaning towards the most ample estimate; for a bystander's difference of opinion may as often arise from his

from the edge, that the workman put it into the upper piece—this can only be done by that sleight of hand which long practice gives, and when this sleight is once acquired the workman can do it with ease, without paying any particular attention, so long as he uses the same tool—but a shoemaker is always sorry when he breaks his awl, because he knows very well that he shall be obliged to serve an apprenticeship of several days before he can acquire the necessary sleight of hand with the new tool—if the new awl is more bent than the old one it will come out nearer the edge than it entered; because its point will describe an arc of a less circle—on the other hand if the new awl is less bent than the old awl, the point will come out at a greater distance from the edge, and the work will have a still worse appearance; hence the workman is obliged to make a series of trials until he can attain the necessary sleight of hand for this purpose. It would be very advantageous if all awls had exactly the same degree of bend—but, unhappily, every maker gives his awl a peculiar bend, to the great trouble of shoemakers and other artists who work in leather."—*Mechanics' Journal*, p. 363.

partial view of the bearings of the question, as the wish of the projector to enlarge or exaggerate.

It has not been so easy a task to insulate the improvements of each artist, so as to prevent their merging into the more imposing labours of names of greater mechanical reputation, and at the same time preserve their proper proportion in the history of the progress of the machine. In noticing these, although brevity was attempted, want of skill may occasionally have made their description too diffuse; but of the two extremes, this, perhaps, will be considered to be the more pardonable.

In the plan of this book, it has not been thought desirable to exhibit those machines only which have been introduced with effect into practice. This limitation, which would have greatly abridged the labour of composition, would at the same time have led to a most erroneous notion of the extent of the ingenuity which has been exerted in bringing steam-engines to their present state of perfection. Many engines are described which have failed upon trial, and these failures have not been considered as good reasons for their being allowed to fall into oblivion, because practice itself is progressive, and those mechanical difficulties which hindered their effective construction may be removed in advancing towards greater perfection. Other machines will be found detailed, of which it is doubtful if their authors ever made them the subjects of an experimental trial; besides, some projects, which in the present state of the mechanic arts, it is probable, would not repay the expense of an experiment: the schemes which have failed, as well as those which are doubtful, have been considered as seeds drifting on a common field, which some random step fixing into

the soil, they may be quickened into life, and springing forth, become estimable for their beauty or usefulness.

It has been easier to find satisfactory reasons for the plan followed in this little work, than for some other circumstances more immediately connected with the compiler. It may have been vanity which, at the commencement of his speculation, flattered him, that what no one had before attempted would be received, if not with favour, at least with indulgence, by those who like himself were busied in the fabrication of steam-engines or in directing their application; besides, from accidental circumstances, the compiler was able to bring together, from his own knowledge, many incidents which others, not so favourably situated as he was, were, perhaps, unacquainted with, and would be gratified by knowing. Any apology for imperfect execution, the compiler is aware, can meet but with few claims to consideration: for, although in a literary view, it was foreign to the routine of his usual employment, the task was one he imposed on himself. During its whole progress, however, he has been suffering from ill health, and the avocations of his profession having the first claim on that time he was able to devote to anything—will, at any rate, account for the protracted appearance of the concluding portion of his volumes. From the same causes, absence from the sources to which alone he could refer for his authorities, will, it is hoped, be some extenuation for his errors of omission; although, from their number, he fears he cannot altogether hope for pardon. It was wished to have supplied these in an Appendix; but the bookseller fearing that a longer delay in the pub-

lication of the book would be detrimental to his interest, this apprehension has induced the compiler to trust to a favourable reception, putting it in his power to add what has been overlooked, or forgotten, in a future impression.

CHAPTER FIRST.

"NEITHER AFFECTING TO CONCEAL THE SMALLER RILLS BY WHICH THE STREAM WAS FED, NOR TO BRING THEM SO MUCH INTO VIEW, AS TO DEPRIVE THE PRINCIPAL OBJECT OF ITS CONSEQUENCE."—*Scott.*

A MACHINE, receiving at distant times and from many hands new combinations and improvements, and becoming at last of signal benefit to mankind, may be compared to a rivulet swelled in its course by tributary streams, until it rolls along a majestic river, enriching in its progress provinces and kingdoms.

In retracing the current too from where it mingles with the ocean, the pretensions of even ample subsidiary streams are merged in our admiration of the master flood, glorying, as it were, in its expansion. But as we continue to ascend, those waters which, nearer the sea, would have been disregarded as unimportant, begin to rival in magnitude, and divide our attention with the parent stream; until at length, on our approaching the fountains of the river, it appears trickling from the rock, or oozing from among the flowers of the valley. So also, in developing the rise of a machine, a coarse instrument or a toy may

be recognised as the germ of that production of mechanical genius, whose power and usefulness have stimulated our curiosity to mark its changes, and to trace its origin. And the same feeling of reverential gratitude, which attached holiness to the spots whence mighty rivers sprung, also clothed with divinity, and raised altars in honour of, the inventors of the saw, the plough, the potter's wheel, and the loom.

To those who are familiar with modern machinery, the construction of these implements may appear to have conferred but slight claim to the reverence in which their authors were held in ancient times. Yet, artless as they seem, their use first raised man above the beasts of the field, and, by incalculably diminishing the sum of human labour, added equally to the power and enjoyment of the barbarous tribes of those ages to which their discovery is referred. In their rudest form they are nearly all the mechanical aids that were necessary for the wants of nations, of shepherds, and of husbandmen.

For refinements, however, in the formation of even these simple contrivances, or for the invention and use of more complex mechanism, we must look to communities that have made considerable advances in the career of civilisation; to those regions where men, congregating in large masses, create numerous artificial wants, and, by this peculiarity in their social position, excite the natural rivalry of individuals to devise expedients to remove them.

Accordingly it is found, that the dense population of some eastern countries had there produced a state of society eminently calculated to call forth the resources of inventive power. From a remote period, the great wealth of the Egyptians

particularly had generated a taste for luxurious magnificence, which that people early displayed in the erection of colossal and sumptuous buildings. The remains of their vast pyramids, temples, and palaces, evince a skilful practice of numerous devices to abridge and facilitate labour, and to give a permanence, almost eternal, to their gorgeous structures.

It is probable that at an era coeval with the raising of these superb fabrics, some of the properties of elastic vapour were known to and applied by the priesthood in aid of the ceremonial of their religion. The statue of Memnon is recorded to have emitted sounds,* which were ascribed to the interposition of superhuman agency; and this widely promulgated notion directing the steps of devotees to the shrine, added greatly to the sacred fame of the temple, of which, in other respects, this image formed a splendid ornament. When the secrets of the waning faith were revealed by the votaries of a rival belief, the celestial harmony was then said to be produced by vapour, rising from water, concealed in a cavity of the statue, being made to pass through a tube, having a small orifice fashioned in a manner similar to that of the pipe of an organ. As long as the fluid was heated by the rays of the sun, mysterious sounds were heard by the assembled worshippers, which died gradually away as the solar influence was withdrawn from the gigantic idol.†

* Many authors have mentioned these sounds. Strabo affirms that he heard them: Pausanias compares them to those produced by the snapping of the strings of a harp. Philostratus says, that when the sun shone strongly on the statue, sounds proceeded from its mouth similar to those of a stringed instrument.

† The explanation in the text is that usually ascribed to

A precocious germ, without a tendency to progression, is characteristic of eastern art. Nations,

Hero, and found in his "Pneumatica." The subject has exercised the ingenuity of many writers. Among the moderns, Solomon Decaus gives a good diagram of a combination for this purpose: he places the figure on a well-closed base, or pedestal, exposed to the sun, and containing water. An organ pipe proceeds from the interior of the pedestal to the mouth of the statue. p. 23. *Raisons des Forces Mouvantes*, Paris, 1629. Kircher displays his usual ingenuity in discussing this topic. His first scheme would produce sounds according with the description of Philostratus. The water is placed in the lower division of the cavity of the pedestal, in a situation to be acted on by the sunbeams. A pipe forms a communication with the upper division, which contains a wheel with vanes, and which is also furnished with tappets; a series of harp wires are likewise placed in the upper part, which are so arranged, that when the vapour issues from the lower into the upper division of the pedestal, through the pipe, it strikes on the vanes; this gives motion to the wheel, and the tappets, as they revolve, are successively brought into contact with the wires. *Œdipus Ægyptiacus, cap. Mechanica Ægyptorum.*

His second scheme is an extension of Decaus's. The sunbeams are concentrated by a series of mirrors upon that part in which the water is concealed. He thinks five reflectors would do the business; but 100, or 1,000 placed in this manner,—"certum est calorem tam intensum fore ut omnia adurere possit et in cineros redigere." p. 886. *Ars Magna Lucis et Umbræ*, Romæ, 1646.

The statue of Serapis moved its eyes and lips at the rising of the sun; and the bird of Memnon flapped his wings, and was accommodated with a voice, it is said, by means of air rarefied by the sun's heat. pp. 327, 328. *Œdip. Ægypt.*

Cribellus, adopting nearly the same arrangement as Kircher, wonderfully extends his idea; he displays a formidable array of wheels, pinions, cranks, and other things to give motion to a bellows for supplying wind to an organ almost large enough for the cathedral of St. Peter: the tones of numerous harp-strings are added to make up a harmony. He concentrates the sunbeams by "parabolas, hyperbolas, ellipses," and other figures, by which, he says, Conos even melted metals; and he doubts not but that the aromatics, (or resins,) which he places along with the water within the pedestal, would be easily inflamed. The rays "derigerent ad vasum et aërem rarefacerent, et aromatæ incenderant, et *aquas* cogerent subsilire, cum autem ex dictis minima vis sufficiat. Non est quod hinc detremen-

almost at the instant of the foundation of their communities, are seen in possession of discoveries, and expert at their application, which are usually considered to be the portion of the most polished societies only, and the fruit of a long career in refinement. Unlike the European races, incessant in their attempts to enlarge the circle of their knowledge and improvement, the Orientals passively remained the willing slaves of first impressions, seldom exerting a power to give those inventions they had so admirably drawn into being, that perfection and extension of which they were so obviously susceptible.

But when, aided by the indolent effeminacy into which the successors of Sesostris had fallen, the enterprise of the Macedonians was crowned by the establishment of their rule over Egypt, the restless energy of these warriors being attempered by the monotonous refinement of its ancient inhabitants, a new and beneficial impulse was imparted to both. During the splendid dominion of her Grecian kings, the arts and sciences of Egypt reached a high degree of excellence; and under one of the Ptolemies, surnamed Philadelphus, and his successors Euergetes I. and II., the court of Alexandria was resorted to as a school of philosophy by the learned and ingenious of many countries. Mechanics, and the kindred sciences, were there held in great esteem; and eminence in

tum aliquod timeamus." He doubts the possibility of Kircher's getting as much vapour as he expected, and thinks his apparatus would give but weak Memnonic groans; but in his own "ut vulcaniam et æoliam obtineremus efficasiorem cujus vi noster Memnon non tenues philomelæ instar gracilescat in modus, sed tonare, effulminare cum pericle possit et mundi parem ditionis amplitudinem, ne dum exiguam Græciam orando valeat permiscere." p. 8. *Machinosa Miracula Memnonis*, Romæ, 1656

their acquirement being opened as a path to personal honour, the boundaries of knowledge were extended, through the exertions of its professors to deserve the countenance of their illustrious patrons.

Among the men of genius who enjoyed the patronage of these munificent princes, one of the most distinguished was Hero the elder, the son of a Greek who had settled at Alexandria. At an early age, the strong bent of his mind towards mechanical pursuits attracted the notice of the celebrated Ctesibius; and the after friendship of that philosopher was the reward of his application and merit. Under his guidance, Hero aspired to celebrity as a follower of Democritus in philosophy; and some beautiful discoveries in mechanics recompensed the study of a long life, assiduously devoted to their cultivation.

The experience of a later time, it is true, has been triumphantly urged as ranking Hero's among other ancient inventions, which may serve as curiosities to amuse our leisure, rather than objects inviting study by a display of useful ingenuity. A candid estimate of a mechanical effort may not, however, be made, by marking its absolute height above every production of a similar kind, but by measuring its elevation above those only placed in its peculiar region. An eminence, conspicuous among the gentle undulations of a champaign country, would be altogether unobserved at the base of a range of mountains. Yet, nevertheless, tried by the high standard of even modern attainment, several of the machines described by Hero* may be compared with the most

* Gli artificiose et curiosi moti Spiritalia de Herone, tradotti de M. Gio. Bapt. Aleotti. Bologna, 1547, reprinted Ferrara, 1589. The figures are beautiful, and were copied from the Greek

useful, or the most ingenious, of those which have been appealed to as proud monuments, placing our own age at an immense distance beyond every other in mechanical invention. The fountain for raising water by the compression of air remains as he left it. The mode of forming a vacuum, by sucking the air from a vessel, and producing a blast by a fall of water, are to be found in the "Spiritalia;" and the construction of the fire-engine was first learnt from his descriptions.

And if the numerous devices in his "Pneumatica" do not all possess the same originality and practical merit, this inequality, objected to as a blemish, will be found to have arisen from a circumstance which adds a grace even to his genius—from his enlightened mind appreciating with a generous liberality the value of the labours of others. Hero, in his introduction, professes to have made himself acquainted with the works of his prede-

MS. All the subsequent translators, except Bapt. Porta, (and his diagrams are in a very vulgar taste,) have copied Aleotti's illustrations. The Bologna edition is very rare.

Heronis Alexandrini Spiritalium liber a Federico Commandino ex Græco in Latinum conversus, 1575. Printed after Commandine's death, with the addition of Aleotti's four theorems on automata, rendered into Latin: this edition was reprinted in an elegant style, at Amsterdam, 1680. Spiritali de Herone Alessandrino ridotti in lingua volgare da Alessandro Giorgi. Urbino, 1592. De Herone Alessandrino de gli automati overo machine moventi libri due: tradotto dal Græco Bernardino Baldi. Venetiæ, 1601. I Tri Libri de' Spiritali de Giovan Batista della Porta, Napolitano, cive d'inalzar acqua per forza dell aria. Napoli, 1606. In the collection, "Veteres Mathematici," Paris, 1693, folio, the Greek text of the Spiritalia is given with a new translation into the Latin, accompanied with Aleotti's theorems on automata. This is a good edition, and common.

Schmidt's Vitam Heronis, Helmstadt, 1714, contains some biographical notices from Baldi and others, and a classification and a summary of his inventions: see also Frobisii's Rudimenta Biographiæ Mathematicæ. Leipsig, 1757.

cessors and contemporaries, to have greatly admired their simple ingenuity, and to have been unwilling that such fine inventions should be overlooked or perish; he described them, therefore, that they might be better understood; and, by placing them among his own contrivances, he not only ensured their being more widely known, but that the knowledge of them would descend to posterity. Having done this, his aim appears to have been accomplished; for, apparently, considering them but as brilliant first thoughts only, they were flung together, and left in a kind of affluent neglect, to be arranged or applied by those who had more leisure and less exuberance of original conception.

In thirteen problems, Hero operates by the action of heat on air or water. In two, the doors of a temple are opened and shut by means of the rarefaction of air, produced by its coming into contact with the heated hearth of an altar; in another, water or wine is raised by the same means, and made to flow on the sacrifice, to assist in its combustion; this is combined with the hissing of a dragon in a fourth; and a rotary motion is imparted to a small stage, on which automata are placed in a fifth. In some of these, however, from the construction of the apparatus, steam of low temperature would be produced, and assist in the action. But throughout, it is not quite obvious that Hero had a notion of the distinction between the heated air and the vapour; or rather, he considered that the vapour owed its power to the *heated air* with which it was combined or mixed. He describes three modes in which steam is used directly as a mechanical power: to raise water by its elasticity; to elevate a weight by its expansive power; and to produce a rotary motion by its reaction on the atmosphere.

On the lid of a box (fig. A*) or cistern, *a*, containing water, Hero places a globe, *c*, also partly filled with the same fluid; a pipe, *e*, rises from the cistern into the globe. Another pipe, *i*, proceeds from the globe, terminating over a vase, *m*, and the vase itself communicates with the cistern by a pipe, *n*.

When the sunbeams fall on the globe, they heat the water, and raise vapour; this, by its expansion, forces the water through the syphon, *i*, which, trickling into the vase, *m*, is again conducted by the pipe, *n*, placed within it, into the cistern. When the sunbeams are withdrawn, and the surface of the globe cooled by the ambient air, the vapour within is condensed, and by this means a vacuum is left in its upper part; the pressure of the atmosphere now forces the water in the cistern up the pipe, *e*, to replenish it, and the same operation of forcing water commences when the sun's rays, falling on the surface of the globe again, heat its contents.

Here, almost under any circumstances, the effect could have been but trifling; but in the second, (fig. B,†) where the heat from a lamp, or

* "47. *Quæ gutta appellatur, stillat sole in ipsam ingruente.* Sit basis præclusa per quam infundibulum impellatur, cujus caulis à fundo paululum distet: et sit sphærula ex qua tubus in basim feratur, à fundo vasis, et à pariete sphærulæ parum distans. Inflexus autem siphon sphærulæ aptatus feratur in infundibulum, et in sphærulam aqua injiciatur. Quando igitur solè in sphærulam ingruit, calefactus aër existens in ipsa humidum expellit. Quod quidem fertur per siphonem et per infundibulum in basim procedit sed cum sphærula obumbrata fuerit excedente aëre, tubus, qui ducitur per sphærulam humidum assumet, et locum exinanitum replebit. Atque hoc toties erit, quoties sol in ipsam ingruet." p. 63. *Heronis Spiritalium Liber a Commandino.* Amst. 1680.

† "45. *Et sphæræ trepudiant hoc modo.* Lebes aquam habens cooperto ore succenditur. Ab operculo autem procedit tubus, ex cujus dimidia sphæra concava simul perforatur. Si

from a fire, is substituted in the place of that proceeding from the sun, the power would not only be more available, but less hypothetical.

A caldron or vase, *a*, has a pipe, *c*, inserted into its lid, formed at its upper end like a small cup, *i*, and containing a ball or hollow sphere, *o*. A fire being made under the boiler, the steam, rising from the water which it contains, flows through the pipe, and lifts up the ball placed in the basin, and keeps it suspended in the air as long as the vapour rises with the proper velocity from the caldron.

A motion round an axis is elegantly given, (fig. C,*) to a small globe, by means of the reaction of steam upon the air. Two pipes, *a*, *c*, each having their upper extremity bent towards each other, rise from the cover of a vase, *o*; one of these, *c*, acts merely as a pivot, the other, *a*, conducts steam, raised in the boiler, into the ball or globe, *i*. This is suspended between them by having the steam-pipe, *a*, inserted into it, and is kept in its position by the pivot formed at the end of the opposite pipe, *c*. Two pipes, *m*, *n*, also bent at right angles at their extremities, are inserted into the circumference of the globe, and

igitur levem sphærulam in dimidiam sphæram injiciamus, continget vaporem, qui ex lebete per tubum attolitur, sphærulam elevare adeo ut tripudiare videatur." p. 62. *Ibid.*

* "50. *Lebete succenso sphærulam ad cnodacem moveri.* Sit lebes succensus, qui aquam habeat obstruaturque osculum cooperculo: et unà cum eo simul perforetur tubus inflexus cujus extremitas concavum sphærulam aptetur. Extremitate autem ex diametro opponatur cnodax cooperculo nixus: et sphæra duous tubulos inflexos habeat secundum diametrum simul cum ipsa perforatus, qui vicissim inflectantur: sint que inflexiones ad rectos angulos continget igitur succenso lebete vaporem per tubum in sphæram incidentem extra cadere per tubos inflexos, et sphæram convertere, quemadmodum in animalibus choreas ducentibus." p. 66. *Ibid.*

form a communication between the caldron and the atmosphere.

Heat being applied to the caldron, the steam, flowing from it through the vertical pipe *a*, into the little globe, *i*, thence finds its way through the pipes or arms, *m*, *n*, into the atmosphere; at this instant the reaction of the vapour on the air makes the globe revolve with a magical celerity, "as if it were animated from within by a living spirit."

These three attempts at employing steam as a mechanical power are described, without even a hint at their extension to any useful purpose. This can detract but little from the merit of Hero; a sagacity little short of prescience could alone have enabled him to anticipate the grandeur of that creation that was to arise from these beautiful but comparatively insignificant beginnings.

That so ingenious a people as the Greeks should not have been led, by those direct experiments, to a practical application of the agent, so exquisitely moulded by Hero into a mechanic power, may, in all probability, be ascribed to the operation of the same causes as those which have thrown a veil of deep and impenetrable obscurity on so many of the arts of antiquity. "The ancient philosophers," says an excellent mechanic, "esteemed it an essential part of learning to be able to conceal their knowledge from the uninitiated; and a consequence of their opinion, that its dignity was lessened by its being shared with common minds, was their considering the introduction of mechanical subjects into the regions of philosophy a degradation of its noble profession; insomuch, that those very authors among them, who were most eminent for their inventions, and were willing, by their own practice, to manifest unto the world

these artificial wonders, were, notwithstanding, so infected by this blind superstition, as not to leave any thing in writing concerning the grounds and manners of these operations; by which means it is that posterity hath unhappily lost, not only the benefit of these particular discoveries, but also the proficiency of these arts in general. For when once learned men did forbid the reducing them to vulgar use and vulgar experiment, others did thereupon refuse those studies as being but empty and idle speculations; and the divine Plato would rather choose to deprive mankind of those useful and excellent inventions, than expose the profession to the ignorant vulgar."

The love of ingenious and refined contrivance, which, notwithstanding the neglect of their philosophers, may be said to have formed a prominent feature in the character of the Greeks, descended not, along with their empire, to the Romans. Improvements in the arts are sought for in vain among these victorious soldiers, during the rise and progress of their iron power; a solitary instance of an application of steam is all that can be gleaned from the historians who described its decline and fall.

"In a trifling dispute between Anthemius, the architect of Justinian, and Zeno the orator, relative to the walls or windows of their contiguous houses, Anthemius had been vanquished by the eloquence of his neighbour Zeno; but the orator was defeated in his turn by the master of mechanics. In a lower room, Anthemius ranged several vessels or caldrons of water, each of them covered by the wide bottom of a flexible tube, which rose to a narrow top, and was artificially conveyed among the joists and rafters of the adjacent buildings; a fire was kindled beneath the caldrons; the

steam of the boiling water ascended through the tubes; the house was shaken by the effort of the imprisoned air, and its trembling inhabitants might wonder that the city was unconscious of an earthquake they had felt; and the orator declared in a tragic style to the senate, that a mere mortal must yield to the power of an antagonist, who shook the earth with the trident of Neptune."

The centuries of turbulence which succeeded, were unfavourable to genius of every kind; useful things were disregarded, because they were common; mystery pervaded every pursuit; inventions could be learnt only by deciphering anagrams; and those contrivances were valued highest for their ingenuity, the principle of which could be the most carefully concealed. In this unfortunate direction given to inquiry, we cease to wonder at the small progress which was made, or that centuries should pass away without a mite being added to the scanty stock of mechanical invention. An organ, described as an object of wonder in the early part of the twelfth century, will not furnish an exception. It shows only that a problem in the "Pneumatica" was resolved with skill even by one of the schoolmen.

About the year 1125, according to the relation of William of Malmsbury, "there were extant in a church at Rheims, as proofs of the knowledge of Gerbert, a public professor in the schools, a clock, constructed on mechanical principles, and an hydraulic organ, in which the air, escaping in a wonderful manner by the force of heated water, fills the cavity of the instrument, and the brazen pipes emit modulated tones through multifarious apertures."

On the revival of learning in Europe, the ancient Platonic contempt of experiment may be said to

have revived with it, and to have infected the Italian philosophers, as it had done those of the East, with an indifference towards useful or practical mechanics. Excepting occasional disquisitions, with a view to the illustration of some part of the works of an ancient author, machines were as heretofore considered to be subjects from which no distinction could arise, and their construction was abandoned to the mechanic, without a single philosopher deigning to stoop from the regions of abstract philosophy, to impart, from the stores of science, a rule, or an observation, to assist the artisan in his labour.

If nothing, therefore, can be added to the history of the employment of steam, a slight interest is attached to the fact, that a knowledge of its power was not extinct; some of its effects were dreaded by lime-burners at this period. In the heart of some stones, according to Alberti, writing in 1412, there are certain voids and concavities, in which air, being shut up, does sometimes produce incalculable mischief; "for when they come to be touched by the fire, and the stone grows hot, it turns *to vapour*, and, bursting the prison in which it is confined, with a tremendous noise, blows up the whole kiln with a force altogether irresistible."

The works of some Greek mathematicians and mechanics attracting the attention of scholars, may be considered an auspicious commencement of a new era, for it was improbable but that a taste for mechanical philosophy should also be formed; and so it followed. Yet, as if the leaven of former prejudice in part remained, the warlike machines of the ancients, which, by the introduction of gunpowder, had become obsolete, were now commented on with ingenuity, and in a great many cases were ably illustrated.

We speak not here of what might be considered the feeling of society towards those who distinguished themselves as speculative mechanics about this period. Whether the imputation of magic, attached to the order, arose through its own pretensions to occult knowledge, or whether astrological practices were forced upon it by the prejudices and ignorance of society itself, the effect on science was nearly the same. Yet, to impute systematic deception to the whole body, would be measuring out unmerited reprobation on numerous individuals of great knowledge, and who discharged the various duties of life with exemplary honour and integrity; and who, by their station in society, and share of its wealth, were far above the practices from the hope of gain. Their pursuit of such trifles, it perhaps were more just to consider as arising from weakness of judgment, rather than corruption of mind; that, in fact, their own reason was first bewildered in the labyrinth of astrology, before their enthusiasm pointed out the distinction that would follow success, in unravelling the mazes of futurity to others; and, if a few unprincipled adventurers sought dupes only among persons of fortune, their avarice should rest as an opprobrium on themselves alone. The tales of the disciple, and master too, in some of these cases, are widely at variance. "He," says the latter, "who called to his aid the venial deference of the wise, but poor man, to sanction actions which it had been more honourable not to have engaged in, or gratify a personal vanity, which by other means it would have been reckoned meritorious to repress, had no good ground of complaint, that the powers of the magician could not be depended upon. But, alas!" says the neophyte, "that so great a price should be set upon that,

which, from sad experience, I now find makes the cost of a grain of mustard seed immeasurably beyond it in value."

One thing is certain, that so long as practical subjects were discarded by philosophers, a wide field was open for the introduction and display of the most unaccountable absurdities; and if now and then something is found to redeem much extravagance, it is so surrounded with rubbish, that the labour of excavation is seldom repaid by the acquisition. Another effect, equally fatal, was less obvious, only because it was deeper seated; exaggerated professions tainting the language of philosophy with hyperbole, absurd expectations deeply infected its spirit. Then, indeed, philosophers appeared like simple men journeying through fertile savannahs, where bountiful nature, at every step of their progress, invites them to supply want from her exuberance; but, despising her profusion, press onward to a toilsome, miserable existence, and inhospitable regions, in which, if they do find gold, it can purchase no enjoyment.

The glory and shame of the fraternity was admirably exhibited in the career of Hieronymus Cardan,* who united the most transcendent attainments with the most consummate quackery, profound sagacity with the weakest superstition; who is seen drawing on one page the horoscope of Christ, and in another, imploring his forgiveness for the sin of having eaten a partridge on Friday; unfolding the most beautiful relations in algebraic analysis, and fore-

* His own account of his *four* grêatest calamities is brief and comprehensive. "The first and greatest is my personal defect;" then "the most cruel death, or folly or barrenness of my children; perpetual poverty, accusations, incumbrances, distempers, dangers, imprisonment; hardship in the so frequent preference of so many worthless persons." *Vita Propria*, p. 259.

telling, from the appearance of specks on his nails, his approach to some discovery; above all, eloquently enforcing the obligations of a pure religion, and expressing the finest sentiments in morals, while his long life was one continued exertion, grossly outraging both. Here this philosopher, juggler, and madman, is entitled to brief mention, from displaying in his writings a knowledge of what has been called some of the "capabilities" of steam, and more particularly with the fact of a vacuum being speedily procured by its condensation. He also early recommended that the heated fuliginous *vapour*, "which escaped from every hearth without performing any useful labour," should be turned to a more profitable account; and in a later book* he gave a description and rude diagram of a machine, moved by heated air, which, since his time, has received no improvement, although much employed, and well

* De Varietate Rerum, lib. xii. cap. 58. Basil, 1557.

From Zonca's book, Roma, 1607; this appears to have been early adapted to the uses suggested by Cardan, and to have had considerable elegance thrown into its form.

His figure of the œlipile is often alluded to by subsequent authors, and it is probable that he was the first who described it.

He quotes Vitruvius as his authority for considering it to have been known andused at Rome in the time of the first Cæsars

known as the smoke-jack. His enumeration of *its* properties are not, at any rate, exaggerated, if its general adoption be held as a test of merit; and after bearing the brunt of the persevering and judicious Count Rumford's long, vigorous, and powerful attack, "nothing curtailed of its fair proportion," it may be considered an invention destined to minister to the most agreeable propensities of many generations of our successors.

Mathesius, a German author, in 1571, displayed almost as much ingenuity in contriving to introduce so untoward a subject into a sermon as a description of an apparatus, answering to a steam-engine, as would be required to invent the machine itself, and which he gives as an illustration of what "mighty effects could be produced by the volcanic force of a little imprisoned vapour."*

Following in the same interesting track, about 1577, another German writer substituted steam in what is called the *whirling œlipile*, as an economical substitute for turnspit labour. Its qualities are, on this occasion, enumerated with selfishness; it is said to "eat nothing, and giving, withal, an assurance to those partaking of the feast, whose suspicious natures nurse queasy appetites, that the haunch has not been pawed by the turnspit in the absence of the housewife's eye, for the pleasure of licking his unclean fingers."†

The greater attention which practical mechanics began about this time to receive from the public, appears to have been the effect, rather than the cause, of some good collections having been made of the machines employed in the arts of the

* Berg-Postilla oder Sarepta von atterly Bergwerk und Metallen, p. 374. Nurimb. 1571.

† Stuart's Descriptive History of the Steam-Engine, p. 8.

period. Besson taught philosophy and mathematics, with great reputation, at Orleans, and acquired celebrity as an ingenious mechanic, by the models of contrivances he exhibited in his lectures. But a more satisfactory record of his merit, than the applause of his contemporaries, remains in a collection of machines* bearing his name, which was published after his death by Beroaldus, in 1578. An anonymous tract, printed at Orleans during the author's lifetime, contains a good account of the expansion of water into vapour by heat.†

Great as was Besson's merit, it had a formidable rival in that of a contemporary; and the excellent Capitano Agostino Ramelli was more fortunate than he by reaping, in his lifetime, the honour due to his ingenuity. Educated at Rome, Ramelli cultivated the fine arts amid the bustle and active duties of a camp; and, as an engineer, united the taste and facility of an artist, with the judgment of an experienced artisan in his delineations of machinery. At the date of the appearance of his book, (1588,) he was then an old man, living at Paris, on a pension from Henry III., into whose service he had entered at an early period, and repaying, by the benefit his labours had conferred on the country of his adoption, for the honour and affluence he owed to the patronage of its monarch.‡

* Theatrum Instrumentorum et Machinarum Jacobi Bessoni cum Franc Beroaldus, figurarum declaratione demonstrativa. Lugduni, 1578.

† "D'une mesure d'eau, par chaleur et atténuation ils s'en font dix d'air, qui tient une grande espace par dessus nous, au contraire par froideur ils s'en font de dix d'air une d'eau." p. 25. *L'Art et Science de trouver les Eaux.* Orleans, 1569. Canini, a Venetian, in 1566, had also made some experiments on this subject.

‡ Le diverse ed artificiose Machine del Capitano *Agostino Ramelli* dal Ponte della Trefia. Ingegniero Christianissimo Re di Francia et de Polonia. A Parigi, in casa del' autore, 1588.

Although this monument of the excellent Capitano's industry and ingenuity may contain nothing strictly entitling him to a notice, in a summary appropriated to a sketch of the progress of steam-engine machinery, yet, as his and Besson's publications may be considered as the first mines whence machinists, throughout Europe, drew the materials of their general improvement, a notice of them can hardly be omitted in any subject of practical mechanics, connected with the period. Here may be observed many fine inventions, which, after having been long forgotten, have been again revived as new; while others have received improvements, almost entitling their authors to claim the merit of original conception.

From the influence these works had on subsequent compilers, it must be regretted that at that time no good model of mechanical description existed to guide the labours of those whose taste or profession led them to describe machinery. The connection, arrangement, and use of the machines are given in these and later works with neatness and perspicuity, and the engravings, as diagrams, are excellent; but any thing relating to the velocities and proportions of their parts is seldom found. This, to the artisan, is a point of essential importance; the efficiency and durability of his handywork mainly depending on his knowledge of these particulars. This want of precision among practical writers, helped not a little also to prolong the reign of visionary speculation, on hypothetical combinations, in that class whose studies had a theoretical direction, and who found it more congenial to their natural indolence to indulge a fanciful genius, by giving the reins of their minds to imagination rather than to reason. Deduction from experiment was unknown to them;

and the *tact*, which often supplies its place, but can be acquired from experience alone, was not theirs. Their mechanical chimeras, however visionary in themselves, might have passed as trifles, and been tolerated as harmless, because carrying evidence of their own absurdity; but they unfortunately had a deeply injurious tendency; being heedlessly considered as lights directing in the path of truth, instead of beacons warning against approach to a precipice of error, they not only produced disappointment, but distracted attention from things which ought to have been followed. The obstinacy with which this philosophical delusion was cherished, marked it as a vigorous shoot of that social Quixotism, whose influence still lingered in the usages, and tinctured the opinions, of society throughout Europe. The same aberration of intellect, which prompted romantic adventure in search of ideal perfection, made the alchymist of the period recklessly cast gold itself into the furnace, in the vain hope of finding among its ashes a talisman for its unlimited reproduction; and mechanics, struck also with the mental pestilence, wasted that "precious stuff that life is made of" in figuring machines, by which mountains could be raised by a child's breathing on small sails attached to a combination of wheels and pinions, and in pursuing the phantom of perpetual motion.*

* Decaus observes, that the multiplication of moving forces is so great, that had he a spot to place a machine on, (as Archimedes boasted,) he could move the earth. He is candid, however, and he says, "It has not yet been put in practice, because there are no such great weights to move; and also that it would be difficult to get a foundation, and a machine strong and solid enough to support "un si pesant fardeau" *Raisons des Forces Mouvantes*, p. 18.

The following quotations, although written long after the

It were, however, injustice to refuse to many, who were obstinate dreamers, the merit of sometimes, by accident, producing inventions of an useful and original character. Notwithstanding a belief in astrology, and a pursuit of alchymy, Baptista Porta, a Neapolitan gentleman, was an expert chymist, and an able mathematician and natural philosopher. His works carried the fame of his acquirements throughout Europe; and, devoting his fortune, as well as leisure, to the advancement of science, his house became the centre of a society in which was to be found every

period alluded to, will give some idea of the extent to which these fancies were carried. They describe vagaries which flourished luxuriantly for centuries, and which are not yet decayed.

"Sampson could lift up the gates of a city on his shoulders; and that the strongest bonds were but as flax burned with fire, and yet his hair being shaved off, all his strength departed from him. By mechanical contrivances, it is easy to have made one of Sampson's hairs, that was shaved off, to have been of more strength than all of them when they were on. By the help of these arts, it is possible (as I shall demonstrate) for any man to lift up the greatest oaks with a straw, to pull it with a hair, or blow it with his breath." The whole apparatus of the engine that will do this, doth consist in two double pulleys, "twelve wheels and a sail." The roots of the oak he estimates to cover a surface of a thousand feet square, and forty feet deep, equal to four thousand millions of pounds weight; "the proportion of the wheels being as ten to one each; if the weight of the straw or hair be equal to the hundreth part of a pound, it will be of sufficient force to pull up the oak; if the wheels and nuts (pinions) be proportioned as a hundred to one, then it is very evident that the same strength of a breath, (blown on small sails,) or a hair, or a straw, will be able to move the world." In another part, supposing "the first wheel to move four thousand turns in an hour, the world would be moved more than a hair's breadth in ten years;" and after a long calculation, "it would not pass one inch in a million of years," saith Mersennus, with some exultation. *Wilkins, Math. Mag.* p. 34. See also *Terra Machinis Mota, by Paulo Cassato*, Roma, 1658, for some extraordinary illustrations.

person distinguished for rank and acquirement in Naples. We owe the magic lantern to his ingenuity; and, in his commentary on the "Pneumatica," (the last made among those in whose language it was first disseminated throughout Europe,) is found a beautiful extension of one of its most interesting propositions. The author, it is admitted, made no application of his apparatus as a mode of raising water, directly by the force of steam, from rivers and fountains; but his *diagram* and descriptions are so complete, that its application to this purpose by another, could not be considered even as a variation of his idea.

A retort, *a*, (fig. C,) has its neck inserted into the bottom of a vessel or cistern, *c*, which is nearly filled with water by the funnel *e*, and well closed; a pipe, *i*, goes through the cover. The water in the retort being heated, steam rises into the upper part of the cistern, and, by its expansion, expels the water it contains through the pipe *i*, inserted into its cover.*

* "Faccisi una casa, *c*, di vetro ò di stagno, e sia nel fondo busato, per dovi passi una canna di un' ampolla da distillare, che sia, *a*, e questa habbi una, ò due oncie d' acqua dentro, e sia il collo saldato nell fondo della cassa, che non possa de la scorrer fuori. Dal fondo della cassa si parti un canale tanto lontano dall fondo quanto basti a scorrer l' acqua, e questo canale passi per lo coverchio fuori pocco lontano dalla sua superficie. Questa cassa si riempi di acqua per il buso, *e*, e doi si ferri bene che non possa respirare. All' ultimo ponerete la detta boccia sopra il fuoco et andate scaldandola pian piano che solvendosi l' acqua in aria premerà l' acqua nella cassa e quella farà violenza all' acqua, che salisca per il canale, *i*, e ne scorra fuori. E così andare sempre scaldando l' acqua sinche sarà finita tutta: e mentre sfumerà l' acqua sempre l' aria premera l' acqua nel vaso e l' acqua uscirà sempre fuori.

"Finita essalatione si misuri quant' acqua sara fuor della cassa, che in luogo dell' acqua usita fuori vi sarà restata tant' aqua. . . . .

The attention which was given to the "Pneumatica" by Italian authors, and among others by Porta, can hardly be accounted for from the gratification of that pedantry, which has been called the besetting sin of the age. Five translations, and other reprints, in so brief a space of time, must have been produced, even among scholars, by something besides a mere admiration of its classical origin.

In the warm climate of Italy, one of the most luxurious accompaniments of a shady grove, a magnificent colonnade, or piazza, is a fountain, or jet of water. Besides the delightful freshness it produces, by giving a motion to the "listless air," the variety of agreeable contrasts water forms with the productions of the statuary and architect, made jets and fountains ornaments which all were ambitious of possessing. To raise water, therefore, in abundance, and to distribute it with judgment and skill, were subjects of such general importance, that any thing teaching the best modes of accomplishing either, could not fail of exciting considerable attention. The "Pneumatica," according to Muratori, which taught a variety of elegant whims, in which water, by simple means, was made to form effects which were so much admired and coveted, received only that attention which was its due, as an admirable practical

"E vi accorgerete della quantità dell' acqua uscita, che l' acqua si e risoluta in tant' aria.

"Si può ancora agevolmente mistrare un' oncia di aria nella sua consistenza in quante parti di aria più sottile si può dissolvere." *I Tri Libri Spiritali*, p. 76. Napoli, 1606.

In another experiment a vacuum is formed by condensation, and water is forced upwards into it by the pressure of the atmosphere: and this is the basis of an ingenious mode of estimating the space into which the air or vapour has expanded. p. 76. *Ibid.*

book; and which, on this account, it would have commanded, had it been first written, instead of being translated by Aleotti. One thing is obvious, that, after his excellent translation, a wonderful variety and elegance of illustration were introduced into hydraulic and pneumatic disquisitions.

The imitation of the style of Italian buildings, also, introduced into other countries the use of ornamental fountains; and Solomon Decaus, a French engineer and architect, was among the first who, following the prevailing taste, gave designs for their construction.

Of Decaus's history nothing is known; but it may be collected from a book he published at Frankfort in 1615, that he was known to, and had been in the service of, Charles I. when Prince of Wales; that he had designed some hydraulic ornaments for that prince's palace at Richmond, and others to satisfy his royal highness's "*gentille curiosité*." Some of these, he says, are described in his "Raisons des Forces Mouvantes," the second part of which he dedicates to Charles's sister, Elizabeth, Electress Palatine. In 1614 he was residing at Heidelberg, from which place he dates his dedications to the king of France, and to the Princess.*

* *Les Raisons des Forces Mouvantes*, avec diverses machines tant utile que plaisantes, auxquelles sont adjoints plusieurs desseins de grotes et fontaines, augmentées de plusieurs figures, par *Salomon de Caus*, Ingénieur et Architecte du Roy. Frankfort, 1615. Another edition, in which the Epitre Dedicatoire is dated Heidelberg, 15th February, 1615, and the permission to print is dated 1614, but it is printed for C. Sevestre, Paris, 1624. A third, with an altered title, "Nouvelle invention de lever l'eau haut que sa source, avec quelques machines mouvantes, par le moyen de l'eau, et un discours de la conduite d'Icelle, avec beaucoup de figures, par *Isaac de Caus*, Ingénieur et Architecte à Charles le Premier, Roy de

In copying the contrivances in the "Spiritalia," as hydraulic and pneumatic machines, Decaus and his contemporaries did not yield either in ingenuity, or love of the marvellous, to any of their Italian precursors; but among much irrelevant speculation and impracticable combination, we begin to observe a leaning to experiment; yet it may be questioned, whether the *partial essays*, which were coming into vogue, did not, in many cases, produce a greater deviation from sober truth, than the pure speculation which preceded them. On a trifling or inconclusive experiment were built the most wonderful mechanisms. Their action was so clearly explained, and their effects so well understood, and so magnificent, "that, by my faith," says a sturdy contemporary, when describing the class, "the very boldness of the projection made unsteady the judgment of right worthy men, who openly spoke, in other matters, their mean opinion of the artists." To Decaus, particularly, the praise of ingenuity and credulity applies in a wide extent; and the prolix earnestness with which he discusses some visionary projects, is only equalled by the apathetic brevity with which he dismisses some exquisite inventions. None of his fancies is so great a favourite as the mode of raising water by the sun's heat. In the "Epitre Dedicatoire," after giving a laconic summary of the contents of his folio, he particu-

Grand Bretagne. A Londres, imprimé pour Thomas Davis, 1667." A fourth edition, with the same title, but without a date or name of the place where it was printed, is "par *Isaac de Caus*, Ingénieur et Architecte, natif de Dieppe." In this the experiments on steam and their diagrams are omitted. This was translated into English by *John Leak*, in 1707. The plates are the same as those in the edition of 1624. The diagrams and experiments on steam are omitted in the translation also.

larly draws the most Christian king's attention to his ingenious appropriation of the solar influence, by which he can perform marvellous effects: a machine acted on by a common fagot being possibly considered, by the "*architecte au roy*," a thing too common to be noticed by so great a monarch.

The principle and arrangement of these whims have been already described; the variations may here only be noticed. Instead of the ball in Hero's problem, Decaus (fig. X) substitutes a box for the water, with lenses inserted into its lid, to increase the sun's heat by concentrating the rays: and in another diagram he places the glasses in a frame, and throws the sunbeams on the outside. The pipe going from the cistern into the heated vessel, he furnishes with a valve opening upwards, to prevent the return of the water; another valve is placed in the pipe rising from the heated vessel, also to perform the same office; as might have been expected, the effect is greatly enlarged in the improved apparatus. Hero was satisfied to make the water he raised a small distance fall in drops; Decaus elevates his to an imposing height, and it descends in copious jets, replenishing ample fountains.

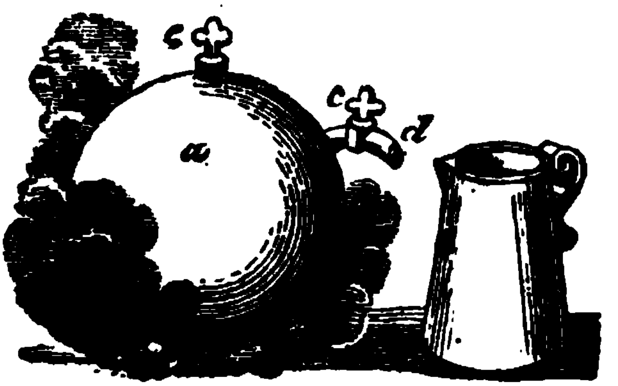
These trifles need not detain us longer from the simpler things, which form his best claim to rememberance, as one of the earliest, though rude, experimenters on steam and appliers of its power to a purpose of utility and importance.

One of his rough experiments will readily recall the source of some later illustrations of the *power* of steam. A well-closed copper ball, which contains a little water, is placed on a fire; when heated, the "compression" of the steam within will burst the globe in pieces, with an explosion

like that of a petard.* In another, he shows how heat carries off the water, into which it enters by evaporation; and, in a third, that steam returns by condensation into its own *bulk* of water;† and

* "Soit une balle de cuivre d'une pied ou deux en diamètre, et espaisse d'un pouce laquelle sera remplie d'eau par un petit trou lequel sera bouche après bien fort avec un clou en sorte que l'eau ny air en puisse sortir, il est certain que si l'on met la dite balle sur un grand feu, en sort qu'elle devienne fort chaud qu'il se fera une compression si violente que la balle crevera en pièces avec bruit semblable à un petart." *Raisons*, &c. p. 2.

† "Soit un vaisseau de cuivre rond marqué *a*, bien clos et soude toute à l'entour, auquel il y aura un tuyau marqué *c*, *d*, dont l'un de bouts, *c*, approchera du fond autant qu'il faut pour laisser passer l'eau, et l'autre bout, *d*, sortira dehors le vaisseau, auquel il y aura un robinet marqué *c*, pour ouvrir et fermer quand besoing sera, et y aura aussi un souspiral en haut marqué *c*, après faut mettre de l'eau dans le dit vaisseau par le souspiral jusques à une certaine quantité, et si le vais-



seau contient trois pots l'on y en mettra justement un pot après faudra mettre le dit vaisseau sur le feu viron trois ou quatres minutes, et laisser le souspiral ouvert puis retirer le dit vaisseau du feu, et un peu après faudra retirer l'eau dehors par le souspiral, et trouverez que partie de la dite eau s'est esvaporée par la chaleur du feu après faudra remplir la mesure du pot comme il estoit auparavant, et remettre l'eau dedans le vaisseau, et alors faudra bien boucher le souspiral et le robinet et remettre le vaisseau sur le feu aussi longtemps comme la première fois, puis le retirer et le laisser refroidir de soy-mesme sans ouvrir le souspiral, et après qu'il sera bien refroidir foudra retirer l'eau de dedans et y trouverez justement la mesme quantité que l'on y aura mise, tellement qu'il se peut voir que l'eau s'estoit s'esvaporée

he propounds in a theorem, that, by means of heat, water will rise to a height above that of its level.* Water is introduced into a copper globe, (fig. B,) *a*, by a funnel; and another pipe, *i*, descends through the fluid to nearly the bottom of the vessel. The globe is placed over a fire; the vapour which is generated in the upper part of the ball, expanding, presses on the surface of the water, and forces it up the pipe *i*, the stop-cock, at *m*, preventing the escape of the steam from the funnel.

Cardan, we have observed, had some clear notions of the properties of steam, but many others of the alchymists are familiar with the facts more directly elicited from Decaus's experiments; indeed, every distillatory process must have forced on their attention the great expansive power of steam; its return by condensation into water; and that the fluid, thus produced, was equal in bulk to that it possessed before it was converted into vapour. But then a simple statement of a plain matter never was sufficient for their sublime imaginations; "some frigorific, ethereal, or ignific" spirit was either to be let loose or bound in chains, or propitiated, before the phenomena could be accounted for or explained. Decaus, therefore,

(la première fois que l'on a mis le vaisseau sur le feu) est retournée en eau la seconde fois que la dite vapeur a este enserré dans le vaisseau et qu'il s'est refroidy de luy-mesme." p. 3. *Ibid.*

* THEOREME. (Fig. 11.)

"L'eau montera par aide du feu plus haut que son niveau dont il se peut faire diverses machines i'en donneray icy la démonstration d'une. Soit une balle de cuivre marquée *a*, bien soudée tout à l'entour, à laquelle il y aura un souspiral marqué *m*, par où l'on mettra l'eau, et aussi un tuyau marqué *i*, qui sera soude en haut de la balle, et le bout approchera près du fond sans y toucher, après faut emplir la dite balle d'eau par le souspiral puis le bien reboucher et le mettre sur le feu, alors la chaleur donnant contre la dite balle fera monter toute l'eau par le tuyau *i*." p. 4. *Ibid.*

ingenious though he be in his labour, marks no progression, unless stating appearances as he saw them may, as it ought, be considered to his honour.

The application of this power was not suggested by Decaus to any purpose beyond that shown in his model. Yet a fire applied, instead of his mirrors, to an arrangement of vessels and pipes, with their cocks, as he describes in his sun's heat machine, (fig. X,) could scarcely have left any thing to be wished for, as a simple, efficient, and ingenious substitute for manual labour in raising water.

The scheme of Branca, an Italian architect and engineer, in 1629, exhibits a different mode of applying the agency of steam; here its impulsion on a wheel produces a rotary motion. The water is heated in an eolipile, *a*, by a fire placed beneath it, *c*, and the steam, issuing from its orifice on the vanes of a wheel, *o*, causes it to revolve; and its continuous motion is communicated to other wheels, moving stampers suspended over mortars.* A

* "Da qual si voglia figura si puo cauare principij et fondamenti buoni per seruirsene all' occasione, la figura è fatta per pestare le materie per far la poluere ma con un motore meraviglioso che non e altro che una testa di metalla con il suo busto segnato per, *a*, empito d'acqua per il foro, *c*, posta sopra carboni accesi nel foculare, *i*, che non possa essalare in altro luoco che nella bocco in sito, *o*, farà fiato cosi violento che voltando la ruota, *n*, et il suo rocchetto, *m*, dara nella ruota dentata, *x*, e con il suo rocchetto, *u*, muouela rota, *z*, quale con il rocchetto, *e*, muoue la ruota, *r*, con il cilindro impernato per alzare li doi pistoni, *s*, *s*, inserti nelli sostegni, *w*, *t*, quale alzandosi a vicenda sopra le vasa di metalla, *s*, si pestarà la poluere et altre materie che bisognaranno, &c." p. 25.

Le Machine. Volume nuovo et di molto artifieio da fare effetti maravigliosi si tanto spiritali quanto di animale operatione arichito di bellissime figure conle dichiarationi a ciascuna di esse in lingua volgare et latina. Del Sig. *Giovanni Branca*, cittadino Romano, Ingegniero and Architetto della Sta. Casa di Loretto. In Roma MDCXXIX.

slight inspection of Branca's diagram will be sufficient to convince us, that his series of wheels, and the stampers and the mortars, are introduced more to show how steam might be applied, than that it ever was so. His book besides is avowedly a collection of machines invented by others; and this mode of moving a wheel by steam, is probably, therefore, an idea of which he is the mere illustrator. He gives another figure in his volume, in which he shows the smoke, rising through a pipe from a *small* smith's hearth, moving a wheel, which communicates motion by other wheels to cylinders, for flattening iron bars. This by the smoke, and that by the steam, may therefore be equally efficient; and both, probably, have similar pretensions to being considered as ever having been applied in practice. The picturesque arrangement of his apparatus will be readily admitted as a proof of the position, at least, that Branca was a man of taste, as well as a person of ingenuity.

The year following that of the publication of Branca's book, the ingenious Cornelius Drebbel, who has left so great a reputation for ingenuity, and so few of whose works remain on which it was founded, put in practice the device which has been described as producing the sounds in the Egyptian idol.

"A musical instrument which, being set in the sunshine, would of itself render a soft and pleasant harmony, but being removed into the shade would presently become silent: the reason of it was this, the warmth of the sun working upon some moisture within it, and rarefying the inward air unto so great an extension, that it must needs seek a vent or orifice, did thereby give several motions unto the instrument.'

Bishop Wilkins,* "a person of rare gifts, a noted theologist and preacher, a curious critic in several

* Dr. John Wilkins, bishop of Chester, married Robinna, the widow of Peter French, and sister to Oliver Cromwell. Archbishop Tillotson married his daughter in law. He was as Wood's character, given in the text, one of the most remarkable men of his time. One of his most curious productions was a discourse tending to prove "that it is probable there may be another habitable world in the moon." This produced much merriment for the wits; among others, the celebrated Duchess of Newcastle objected to the doctor's proposition, "that it is possible for some of our posterity to find out a conveyance to this other world," and suggested the want of *baiting places* on the way; the Doctor's reply was an expression of surprise, "that this objection should be made by a lady who had been all her life building *castles in the air*." "If it be inquired," says the bishop, "what means there may be for our ascending beyond the sphere of the earth's magnetical vapour, I answer. 1. It is not, perhaps, impossible that a man may be able to fly by the application of wings to his own body; as angels are pictured, and as Mercury and Dædalus are fained; and as hath been attempted by divers, particularly by a Turk in Constantinople, as Busbequius relates. 2. If there be such a great ruck in Madagascar, as Marcus Polus the Venetian mentions, the feathers in whose wings are twelve feet long, which can scoope up a horse and his rider, or an elephant, as our kites doe a mouse; why then it is but teaching one of these to carry a man, and he may ride up thither as Ganymede does upon an eagle. 3. Or if neither of these ways will serve, yet I do seriously, and upon good grounds, affirm it possible, to make a flying chariot, in which a man may sit and give such a motion unto it as shall convey him through the air; and this, perhaps, might be made large enough to carry divers men at the same time, together with food for their *viaticum*, and commodities for traffique. It is not the bigness of any thing in this kind that can hinder its motion, if the motive faculty be answerable thereunto. We see a great ship swim as well as a small cork; and an eagle flies in the air as well as a little gnat. This engine may be contrived from the same principle by which Archytas made a wooden dove, and Regio Montanus a wooden eagle. I conceive it were no difficult matter, if a man had leisure, to show more particularly the means of composing it. The perfecting of such an invention would be of such excellent use, that it were enough to make a man, but the age also wherein he lives; for, besides the strange discoveries that it might occa-

matters, and an excellent mathematician and experimentalist, and one as well seen in mechanism and new philosophy, of which he was as great a promoter, as any man of his time," in 1648, mentioning Cardan's idea,* describes another use

sion in this other world, it would also be of inconceivable advantage for travelling above any other conveyance that is now in use; so that, notwithstanding all those seeming impossibilities, 'tis likely enough that there may be a means invented of journeying to the moon; and how happy shall they be that are first successful in the attempt."

"Might not a 'high pressure' be applied with advantage to move wings as large as those of the 'rucks,' or the 'chariot.' The engineer might, probably, find a corner that would do for a *coal-station*, near some of the 'castles.'"

* In addition to the uses of the smoke-jack enumerated by Cardan, the bishop mentions "chiming of bells, or other musical devices; and there cannot be any more pleasant contrivance for continual and *cheap music*: it may be useful also for the *reeling of yarn*, the *rocking a cradle*, with divers like domestic occasions." *Math. Mag.* p. 86.

In the books on heating buildings, the first application of steam to this use is ascribed to a Colonel William Cook in 1745. But in a posthumous work of Sir Hugh Platte, published in 1660, it is suggested as a mode of heating a conservatory: "and for the keeping of any flowers or plants abroad, as also of those seeds thus sowed within doors, or any other pots of flowers or dwarf-trees in a temperate heat, with small charge you may perform the same, by hanging a cover of tin, or other metall, over the vessel wherein you boil your beef, or drive your buck, which having a pipe in the top, and being made in the fashion of a funnel, may be conveyed into what place of your orchard or garden you shall think meet; which room, if it were so made as that at your pleasure it may become either close or open, you may keep it in the nature of a stove in the night season, or in any other cold weather, and in the summer time you may use the benefit of the sunbeams to comfort and cherish your plants and seeds; and this way, if I be not deceived, you may have both oranges, lemons, pomegranates, yea, peradventure, coloquintida, and pepper trees, and such like. The sides of this room, if you think good, may be plastered, and the top thereof may be covered with some strained canvas to take away at your pleasure. Quere if it be the best to let the pipe of lead to breathe out at the end onely, or else at divers small vents

to which the Italian steam-wheel could be applied with advantage. "The œlipiles," says the bishop, "are concave vessels, consisting of some such material as may endure the fire, having a small hole at which they are filled with water, and out of which, when they are heated, the air doth issue with a strong and lasting violence, are frequently used for exciting and contracting of heat in the melting of glasses and metals; they may also be contrived for sundry other pleasant uses, as for the moving of sails in a chimney-corner, the motion of which may be applied to the moving of spits or the like."

The idea broached so ingeniously by Porta, did not escape the research of the laborious Kircher, a Jesuit, celebrated for his profound reverence for antiquity, and who taught philosophy with applause at Rome. But mingling the greatest prejudices of his age with valuable facts and sagacious inference, the air of trifling which was given by this means to otherwise meritorious discussion and research, impressed his own works with a premature old age: even in his lifetime, his immense folios had nearly become obsolete; and now when they are alluded to, it is more from the circumstance of his literary voracity being discovered to have preserved something which was either thought to have been lost, or which was not known had been in existence. From one of his gorged and neglected volumes a

which may be made in that part of the pipe which passeth along the stove. I feer that this is but a meer conceit, because the steam of water will not extend far; but if the cover to your pot be of metal, and made so close that no air can breathe out, saving at the pipe, which is soldered or well closed in some part of the cover, then it seemeth probable that this cover may be put on after the pot is scummed." p. 19. *Garden of Eden*. 1660.

beautiful experiment is drawn forth, in which he applies, in a direct and masterly manner, the power of steam to raise water. In this particular instance, too, the evidence is complete, of his having applied the speculation to practice. The model he describes in 1656, in terms of admiration, was stated by Bonnani, many years after his death, as existing in the museum which Kircher had collected.*

A boiler, *a*, (fig. A,) containing water, is connected by a pipe, *c*, with another vessel, *e*; from this vessel, which is well closed, another pipe, *o*, rises into the atmosphere. The fire being kindled under the lower vessel, containing water, steam issues from the pipe, and, filling the upper part of the superior vessel or cistern, its expansion forces the water it also contains up the pipe into the atmosphere. The scheme in Branca's book also receives a farther extension. Branca employed one head to vomit forth the steam;

* Kircher employed a mechanic, called George de Sepi, to construct his models. Sepi printed a catalogue, at Amsterdam, of his master's museum. Moreri, vol. iv. p. 59.

"Ut his elementorum magnetismus, magis magisque pateat cum artificiosis, machinis demonstrandum duxi, quæ quidem machinæ quintuplici ratione instituenda sunt, ita ut aliæ despulsiva quædam attractiva nonnullæ rarefactiva aliquæ condensativa cæteræ compressi aëris violentia operationes suas instituant, quas qui moverit quaslibet sibi ingeniosas machinas ad exemplar naturæ fabricatas conficiet, cum nulla machina hydraulica aut meteorologica, assignari possit, quæ non aliqua harum facultatum instituatur, atque ut hæc omnia clarius innotescant a machina depulsiva vi operationes suas perficiente inchoabimus." The action of the steam on the water in the upper vase is correctly described: "verum alio jam liquore stationem vasis occupante in intolerabiles angustias redactus aliisque identidem rarefactis partibus subtilior es subtilior factus gravum init cum aqua luctam, aut igitur vas rumpatur aut aqua cedat recesse est." p. 413. *Magnes sive de Arte Magnetica.* Coloniæ. 1643.

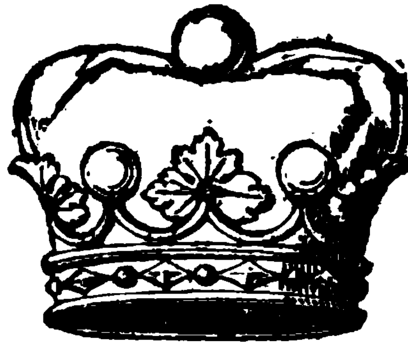
Kircher greatly increased its effect, by employing two; and if Branca's was picturesque, so is Kircher's.

The use made of steam from æolipiles by Branca, Wilkins, and Kircher, will excuse a brief notice of the fact of their being employed in England in very early times to excite the heat of a fire. Dr. Plot, in his account of Staffordshire, describes a manorial custom, which he supposes had continued from the age of Godiva, the famous wife of Leofric, Earl of Mercia. "Jack of Hilton," says the doctor, "a little hollow image of brass, about twelve inches high, with his right hand on his head, and his left on pego," blows the fire in Hilton-hall every new year's day, while the lord of Essington drives a goose three times round it, before it is to be roasted and eaten by the lord of Hilton, "or his deputy;" and in 1594, Sir Hugh Platte gave a good figure of a "rounde ball of copper, or latton, that blows the fyre verie stronglie, by the attenuation of water into ayre."

Kircher.

CHAPTER SECOND.

"IF EVERY THING WHICH WE CANNOT COMPREHEND IS TO BE CALLED AN IMPOSSIBILITY, HOW MANY ARE DAILY PRESENTED TO OUR EYES; AND IN CONTEMNING AS FALSE THAT WHICH WE CONSIDER TO BE IMPOSSIBLE, MAY WE NOT BE DEPRECIATING A GIANT'S EFFORT TO GIVE AN IMPORTANCE TO OUR OWN WEAKNESS?"—*Montaigne.*



THE realities of the Marquess of Worcester's life have all the air of a romance. At the period of his birth in Ragland castle, his family was considered to be the most wealthy among the nobility, and not inferior to any of its rank, in ancient chivalric and honourable lineage. His father, the fifth earl of Worcester,* took an active part with the cavaliers in the civil war; and when King Charles appealed to the sword, the marquess (then Lord Herbert) was intrusted with the command of a large body of soldiers,† mostly raised in his native county, and the adherents of his family. After the surprise and capture of Monmouth by the parliamentary army, Lord Herbert, by a prompt and sudden movement, contrived, un-

* "A worthy and disinterested man, living with credit and character at his castle of Ragland, during the peaceable part of King Charles's reign, and defending it for him till the very conclusion of the war at his own expense, it being the last garrison that surrendered. The marquess, the richest of the peers, spent his fortune in the cause, and died a prisoner soon after the demolition of his castle; the articles of capitulation having been violated." Walpole, *Royal and Noble Authors*, vol. i. p. 376.

† Fifteen hundred foot and five hundred horse. It cost the marquess about 60,000*l*., but being quickly annihilated, produced no effect. *Cox's Tour in Monmouth*, p. 216.

perceived by his opponents, to lodge a squadron, with which he was detached from Ragland, behind a rising ground in the vicinity of the provincial capital; at the head of a small party of volunteers, he scaled a redoubt, passed the ditch, put the guard to death, and thus forcing a way for his cavalry, who at that instant joined him, he dashed sword in hand into the town, and made the garrison prisoners. This daring achievement established his reputation for courage and enterprise.

Receiving the title of Earl of Glamorgan, he was soon afterwards sent into Ireland; but here his natural impetuosity hurried him into positions, which were not considered favourable to the cause of the king, nor to his own honour.* The share he had in the negotiation to bring over a body of Irish, being artfully exaggerated by his enemies, the popular feeling set so strongly against him, that he found it prudent to seek safety from its virulence, by crossing the sea.

* Lord Glamorgan's own feeling of the part he acted in this transaction will best appear from one of his letters, written when he was in Dublin castle, to his wife, a daughter of O'Brien, Earl of Thomond.

"My dear Heart,—When I consider thee a woman, I feare, least you should be apprehensive; but when I reflect, that you are of the house of Thomond, and that you were once pleased to say these words unto me, that I should never in tendernesse of you desist from doing, what in honour I was obliged to doe, I grow confident, that in this, you will now show your magnanimity, and by it the greatest testimony of affection that you can possibly afford me. I need not tell you how cleare I am, and voide of feare; the onely effect of a good conscience; and that I am guilty of nothing that may testifie one thought of disloyalty to his majestie, or of what may stain the honour of the family I come of, or set a brand upon my future posteritie. Courage! (My Heart,) were I among the king's enemies, you might feare, but being onely a prisoner among his friends and faithfull subjects, you need doubt of nothing, but that this cloud will be soon dissipated by the sunshine of

To fill up the cup of his misfortune, Ragland castle was besieged; and, after being defended by his father with the courage of an old Roman,* it surrendered at last upon honourable conditions; these, however, were perfidiously broken, and the venerable nobleman survived the catastrophe but a few months. The ruin of the family now seemed complete; the seat of its splendour was destroyed; its majestic woods were consigned to the axe, and sold; its domain was alienated;† and its chief was an exile.

the king my master." The sacrifice that Lord Worcester willingly made of himself to save the appearances of honour in his temporising master, was well understood at the time by both parties. "Letters from the west inform us that one Captain Patricke Allin, with one-and-twenty more, all natural Irish, in a frigot, put in at Padstow, in Cornwall, little thinking it to be in the parliament's power, with letters to the Prince and Hopeton, from the Earle of Glamorgan, which letters, together with the frigot and men, were seized on by the country people with the help of some of our soldiers: the men all slain but two, who were carried before his excellency Sir Thomas Fairfax, and examined: much is discovered of the *jugglings* between the King, Ormonde, Digby, and Glamorgan, who was so *speciously accused and committed for his exceeds*, and abusing of his majesties authority, in contracting with the Irish, contrary to his majesties intention, as lately by a letter his majesty publicly declared; this, notwithstanding, Glamorgan is employed to bring over the Irish." *Weekly Intelligencer*, Tuesday, March 10, 1645. "I have often heard of his majesties hocus pocus, but that a king should prove a hocus pocus himself, and cast a mist before the eyes of his people, is such a wonder as much to exceed our comprehension and belief." *Mercurius Civicus*, March 11, 1645.

* "The summons," (to surrender,) says the marquess in answer to it, "makes it too evident that it is desired that I should die under a hedge like a beggar; have no house left to put my head unto, nor means left to find me bread; wherefore, to give you answer, I make choice (if it so please God) rather to die nobly, than live with infamy." Rushworth, p. 214.

† "Thirty-seven thousand cords of wood were cut down. The lead was sold at Bristol for 6,000*l*." In the same book is a list of the marquess's *household*; and the author observes,

During the ascendancy of the parliament, the marquess resided abroad.* When again, in an unfortunate hour, accepting a commission from the king, he proceeded to London on some secret purpose; being there quickly recognised, he was committed (in 1656) a close prisoner to the Tower. Here his necessities were many and great;† but here, according to a tradition, his attention was first drawn to the amazing force of steam, by observing the rising of the lid of a vessel employed in a culinary operation in his chamber; and from this circumstance he projected that machine, which has thrown round his name so bright a radiance.

The return of the king gave the marquess a home, but in his old age he was doomed to feel all the miseries of hope deferred. The ear of his royal master was closed by the intrigues of enemies, or by ingratitude; and the man who had spent the fortune of a prince in the cause of royalty, was left, at its final triumph, nearly in a

that from the "contemplation of the scene of almost *regal splendour* which it exhibits, the fortune of the first nobleman in the land, at the present day, would be scarce sufficient to maintain the *household* at *Ragland*." Heath's *Ragland*, 1806.

* His son enjoyed the friendship and patronage of Cromwell, who gave him a pension of 2,000*l.* a year. The protector, however, held, by a grant, a large part of the confiscated estate of the father. In 1682 he was created Duke of Beaufort by Charles II.

† In a letter to Colonel Copely, dated March, 1656, he says, "I know not with what face to desire a curtesy from you, since I have not yet payed you the five pounds, and the mayne businesse so long protracted, whereby my reallity and kindnesse should with thankfulnesse appeare; yet, in the interim, my disappointments are soe great, as that I am forced to begge, if you could possible, either to help me with tenne pounds to this bearer, or to make use of the coach, and to goe to Mr. Clerk, and if he could this day help me to fifty pounds, then to pay yourself the five pounds I owe you out of them. The alderman has taken three days time to consider of it."

state of destitution, oppressed with debt, and without resources.

The tædium of his long imprisonment was beguiled by mechanical amusements, which, it is gathered from other sources, he diligently followed even in the times of his brightest fortunes,* and in situations apparently the most unpropitious for his being able to spare the necessary leisure and attention. At his enlargement, neither the dilapidation of his fortune, the love of pleasure, which

* "At the beginning of the long parliament, there were certain rustics who came into Ragland castle to search for arms, my lord being a papist. The marquesse met them at the castle gate, and desired to know whether they had come to take away his money, seeing they intended to disarm him. They answered no, and after some sharp and dubious words coming from the marquesse, they were at last willing to take his word; but the marquesse not willing to part with them on such easie terms, having before resolved to return them one fright for another. Having carried them up and down the castle, he at length brought them over a high bridge, that arched over the moat, that was between the castle and the great tower, wherein the *Lord Herbert had lately contrived certain water-works, which, when the several engines and wheels were set agoing, much quantity of water through the hollow conveyances of the aquaducts, was to be let down from the top of an high tower.* Upon the first entrance of these wonderful asinegoes, the marquesse had given orders that these catarrhacts should begin to fall, which made such a heideous and fearful noise, by reason of the hollownesse of the tower, and the neighbouring echoes of the castle, and the waters that were both between and around them, that there was such a roaring, as if the mouth of hell had been wide open, and all the devils had been conjured up, that the poore silly men stood so amazed, as if they had been half dead, and yet they saw nothing. At last, as the plot was laid, up comes a man, staring and running, crying out before he came at them, "Look to yourselves my masters, for the lions are got loose;" whereupon the searchers gave us such a loose, that they tumbled so over one another, down the stairs, that it was thought one half of them had broken their necks, never looking behind them until they were sure they had got out of sight of the castle." *Apophthegms*, p. 87. 1682.

was strongly implanted in him, nor his own increasing infirmities, had any effect in damping the ardour of his enthusiasm: when other minds would have sunk under the neglect and distress of his situation, his appeared like a beam of the palm-tree, fabled by the ancient builders to spring upwards against its load with an energy, increasing as the burden was augmented.

The desire of being useful to his country, in the way which his experience pointed out was of all others the most effective, gained strength as his offers of service were rejected. Yet he solicited but for that cheapest of all patronage, the countenance only of men in power, to ensure a fair trial for his inventions: for notwithstanding his deep embarrassments, so sanguine was he of the practical value of his projects, that he offered to make all the experiments at his own expense. The passage is curious. "Be pleased," he says to parliament, "to make use of me and my endeavours, to enrich them not myself; such being my onely request unto you, spare me not, in what your wisdoms shall find me useful, who do esteem myself, not onely by the *act* of the water-commanding engine (which so chearfully you have past) sufficiently rewarded, but likewise with courage to do ten times more for the future; and my debts being paid, and a competency to live according to my birth and quality settled, the rest I shall dedicate to the service of our king and countrey by your disposals; and esteem me not the more, or rather any more, by what is past, but what's to come; professing really from my heart that my intentions are to outgo the six or seven hundred thousand pounds already sacrificed, if countenanced and encouraged by you; ingenuously confessing

that the melancholy which hath lately seized upon me (the cause whereof none of you but may easily guess) hath, I dare say, retarded more advantage to the public service than modesty will permit me to utter. And, now revived by your promising favours, I shall infallibly be enabled thereunto, in the experiments extant and comprised under these heads, practicable with my directions, by the unparalleled workman Caspar Kaltoff's hand, who hath been these five-and-thirty years as in a school under me employed, and still at my disposal, in a place by my great expenses made fit for public service, yet lately like to be taken from me, and consequently from the service of king and kingdom, without the least regard of above ten thousand pounds expended by me, and through my zele to the common good."

The book to which he alludes as containing the "heads" of his experiments, was published in 1663, under the title of "A century of the names and scantlings of such inventions, as at present I can call to mind to have tried and perfected, which, my former notes being lost, I have, at the instance of a powerful friend, endeavoured, now in the year 1655, to set down in such a way, as may sufficiently instruct me to put any of them in practice."

The novelty of the greater number of the hundred propositions or descriptions of which this volume consists, and the wonderful nature of others, cast an air of improbability over the whole: the noble author was charged with describing many things which he wished were invented, rather than machines which he had actually constructed. And even those who have been warmest in praise of his genius, and have spoken in favourable terms of some of his "scantlings,"

have found it necessary to enter their protest against others, in order to save their own consistency.*

Yet this collection of descriptions bears internal marks of being what it professes to be, drawn up from actual trials of machines in existence. On an attentive examination of the general scope of his inventions, they will appear to have been suggested, the greater number, by the wants of his accidental situation; and a small number by those of his station. To a statesman employed in highly confidential negotiations, the secrecy of his correspondence would be of the greatest importance; to a traveller the security of his locks; a soldier is mainly interested in his

* Whatever credit may be attached to his assurances of having carried his contrivances into practice, and by which he sought to gain nothing, it is certain that there is no instance in English history of such unbounded confidence being placed in the honour of any individual, as was placed in the marquess by those who knew him well, and had observed him long in circumstances that mankind generally consider to be unfavourable to disinterestedness; every thing appeared to tempt his vanity as well as try his integrity; yet on these points even his enemies have been silent. Lord Orford's statement may be taken, without a fear of its being partial to the marquess, as to the extent of this confidence. "It is certain that he and his father wasted immense sums in the king's cause, of all which merits and zeal his majesty was so sensible, that he gave the earl the most extraordinary patent that ever was granted; the chief powers of which were, to make him generalissimo of three armies, and admiral, with nomination of his officers; to enable him to raise money by selling of his majesty's woods, wardships, customs, and prerogatives; and to create by blank patents, to be filled up at Glamorgan's pleasure, from the rank of marquess to baronet. If any thing could justify the delegation of such authority, besides his majesty's having lost all authority when he conferred it, it was the promise with which the king concluded, of bestowing the Princess Elizabeth on Glamorgan's son. It was time to adopt him into his family when he had into his sovereignty." *Walpole's Royal and Noble Authors*, vol. iii. p. 96.

arms, at times in scaling a fortification, or transmitting intelligence in the dark; and the projector of a water-company could not fail of laying his ingenuity under contribution, to devise a mode of raising water above its level. These classes comprise the greater part of his hundred inventions; and when we learn that, for so long a period as thirty-five years, he employed an expert mechanic in his various projects, it is a matter of wonder that his inventions were not more numerous. And in fact, he says that they were so; for he observes, "that he has omitted many, and some of three sorts not willingly set down, lest ill be made thereof;" but that such things were actually within his knowledge is quite clear, for he promises to "set them down in his own cipher, not to be concealed when duty or affection obliges him." It is also very generally admitted, that not a few of his improbable things are trifles, while others usually conceded to him as conveying clear notions, are decidedly machines of importance; and all are agreed, that since his book was published, many similar contrivances have been put in practice.

There is nothing therefore preposterous in the opinion, that *all* the inventions described in the "Century," had been put by the noble mechanic to the test of experiment. Of one, which is the subject of the sixty-eighth proposition, we have fortunately very conclusive evidence *of its having been actually erected*, and this may be considered as that one the most obscurely hinted at, and described as capable of the most improbable performance of all his inventions. The announcement is as follows:—

'An admirable and most forcible way to drive up water by fire, not drawing or sucking it up-

ward, for that must be as the philosopher calleth it, *infra sphæram activitatis*, which is but at such a distance, but this way hath no bounder, if the vessels be strong enough; for I have taken a piece of a whole cannon, whereof the end was burst, and filled it three-quarters full, stopping and screwing up the broken end, as also the touch-hole, and making a constant fire under it; within twenty-four hours it burst, and made a great crack, so that having found a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other, have seen the water run like a constant fountain forty feet high; one vessel of water rarefied by fire driveth up forty of cold water; and a man that attends the work, is but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with cold water, and so successively."*

This description, although obscure, would give a mechanic a pretty clear notion of the rationale of this machine; yet that might be a rude contrivance compared with a modern steam-engine on any construction. It was reserved, however, for an ingenious correspondent in a provincial periodical,† to point out the connection between this description, and two others, forming the ninety-eighth and one hundredth propositions, and thus supplying from all the deficiencies in each.

"An engine so contrived, that working the *primum mobile* forward or backward, upward or downward, circularly or corner-wise, *to* and *fro*, straight, upright, or downright, yet the pretended operation continueth and advanceth, none of the

* Century of Inventions, p. 52. London, 1663.
† Glasgow Mech. Mag. vol. ii. p. 316.

motions above-mentioned hindering, much less stopping, the other; but unanimously and with harmony agreeing, they all augment and contribute strength unto the intended work and operation; and therefore I call this a *semi-omnipotent engine*, and do intend that a model thereof be buried with me."*

"How to make one pound weight to raise an hundred as high as one pound falleth, and yet the hundred pound descending, doth what nothing less than one hundred pounds can effect."

"Upon so potent a help as these two last-mentioned inventions, a waterwork is, by many years' experience and labour, so advantageously by me contrived, that a child's force bringeth up, an hundred foot high, an incredible quantity of water, even two foot diameter, so naturally, that the work will not be heard into the next room; and with so great ease and geometrical symmetry, though it work day and night from one end of the year to the other, it will not require forty shillings reparation to the whole engine, nor hinder one day's work; and I may boldly call it *the most stupendous work* in the whole world: and not onely with little charge to drain all sorts of mines, and furnish cities with water, though never so high seated, as well as to keep them sweet, running through several streets, and so performing the work of scavengers, as well as furnishing the inhabitants with sufficient water for their private occasions; but likewise supplying rivers with sufficient to maintaine and make them portable from towne to towne, and for the bettering of lands all the way it runs. With many more advantageous and yet greater effects of profits, admi-

* Century of Inventions, p. 72.

ration, and consequence; so that, deservedly, I deem this invention to crown my labours, to reward my expenses, and make my thoughts acquiesce in the way of further inventions."*

The *primum mobile* is here, evidently, the force of steam, that, flow in whatever direction it may, is still capable of exerting the same mechanical power; and the movements, however numerous, can be made not to interfere with each other. The fall of a pound weight raising a hundred pounds weight, clearly refers to a mechanism like a piston; one weighing a pound, attached to a lever, would raise one hundred pounds as high as one pound falleth; and were this weight of water to fall on a water-wheel, for instance, as is now often practised, it would raise a quantity very nearly equal to its own weight, and to the same height from which it fell. A child's force, too, would be sufficient to turn a cock of even a large engine; and the small noise made by this description of machinery, and its working day and night without intermission, or impairing its power, are circumstances in the use of the machine now familiar to every person. It would be difficult to give a *clearer* description of the action of a

* *The Century of Inventions*, printed at *London* in 1663, was reprinted at *London* in 1746; at *Glasgow* in 1767; at *Kyo*, *Lancashire*, 1778, with a short historical notice of the steam-engine. Another reprint is dated *London*, 1786; a sixth *London*, 1813; and a seventh *London*, 1825.

All the problems contained in the "Century" were printed in the Gentleman's Magazine for 1748, with notes pointing out solutions which *had* been given of some of the "scantlings." This is an ingenious commentary. The definitions are also to be found in vol. ii. of *Gregory's Mechanics*. The second volume of the *Mechanics' Magazine* contains by far the best reprint of the *entire* treatise that has appeared. In this will be found the variations of the printed copies from the MS. in the British Museum.

steam-engine, in general terms, without a special explanation of its minutiæ and principles. In this case, however, it obviously was the intention of Lord Worcester to conceal both.

"That he did not carry all his ideas into execution," says Mr. Wallace, "does not seem to have been so much his fault as that of the age in which he lived;" but the doubt of his having put them into practice is greatly lessened, by considering his perseverance, and his means. We have seen that for thirty-five years he employed an ingenious mechanic, under his own eye: these must have been spent on something; and why not on those things described in his "Century of Inventions," and especially on his machine for raising water by the force of steam? It would be almost impossible to describe effects so clearly as he has done, without actually looking at a machine in action.

The apparent impossibility of *some* of his projects has already been noticed, as affording to many a reason for placing but a small value on the entire collection. "To raise a hundred pounds weight," say the cavillers, "as high as one pound falleth, by the weight of that pound alone, carries absurdity on the face of it." And certainly it must be admitted, that a *literal* construction of this proposition would justify all the charges which have been made to the prejudice of its author. That the marquess, however, did not propound it to be construed so literally as it has been, very evidently appears from an account of his inventions, which is still extant in manuscript, but which has hitherto escaped the notice of his admirers as well as of his detractors. The summary is contained in two sides of a leaf of post paper; it is written in a fine ancient hand,

and appears to have been copied with care from an original paper, written by Lord Worcester; but whether before or after the date of the publication of his "scantlings," there is now no means of ascertaining.*

* "INVENTIONS OF YE EARLE OF WORCESTER.

"The Quint Essence of motion, or a collection of all kinds of movements, to wit, circular to and fro; perpendicular upwards and downwards; side motions to ye right and left; straight motions forwards & backwards, with a circular Vehiculum, to wch any of these may bee applicable or moveable to all ye points of ye compasse: at each of wch, it will bee as powerful as if it were first to one place or Center.

"All and every of these by hight of Art, Industry, & Experimt working ye same Individuall & Intrinsecall effect without disturbance to ye other; & yet by these absolutely contrary Motions soe performed, most strange and incredible Effects may bee brought to passe to ye Admiration even of ye greatest Mathematicians.

"The knowledge of these things, rendering all things as feasible to him, yt is Master of this Art, as it is to make a circle with a paire of Compassess, or a straight line wth a Square or Ruler. They beeing a direct abstract of Arithmetick, contrived by mee. And by ye power of those I have perfected these following Conclusions, wth some hundreds besides, all experienced by mee.

"1. I can render an ordinary Watch, wch beeing once wound up, will goe constantly during a Man's life, beeing used but once in 24 houres, & (though oftner look't on:) it is still ye same, and though not look't on for a weeke, still ye same if not bruised.

"2. By this I can make a Vessel of as great burthen, as ye River can beare, to goe agt ye streame, wch ye more rapid it is, ye faster it shall advance, and ye moveable part yt workes yt may be by one man still guided to take ye best advantage of ye streame, & yet to steer the boat to any point. And this Engine is applicable to any Vessell or Boat whatsoever; without being therefore made on purpose; and worketh these effects. It roweth, it draweth, it driveth (if need bee) to passe London-bridge agt ye streame at low water. And a boate lying at Anchor, the Engine may be used for loading or unloading.

"3. By this I can make an Artificiall Bird to fly wch way & as long as I please.

In this interesting document (which is given *entire* in the note) the incredible proposition is stated, with a *qualification*, through which even

"4. By these I can make a ball of silver or gold, wch, throwne into a pale or poole of water, shall rise againe to ye perfect houre of any day or night. The superfices of ye Water shall still show the houre distinctly, even ye minutes, if I please.

"5. By this I can make a Childe in a coach, to stop ye horses (runing away) and shall be able to secure hime, & those yt be in ye Coach having a little Engine placed therein, wch shall not bee perceived in what posture soever ye horses draw: a Childes force shall bee able to disengage them from overturning ye Coach or prejudicing any body in it.

"6. By these I can make one pound raise an hundred as high as ye one pound falls, & ye one pound taken off ye 112 lb. shall againe descend performing ye intire effect of an hundred waight; (*i. e.*) I have yt force wch nothing lesse than 112 lb. can have any other way. An incredible effect till seene, but true as strange.

"7. By these a childe shall raise as much water 100 foot high (speaking within compasse) as 6 horses can force up any other way.

"8. By these I can stop any other Man's motion and render it null, since from any point of ye compasse I can forceably and effectually cause a counterbuffe, or absolute obstruction of such Motion, wch way I please. All wayes beeing indifferent to mee to worke a perfect resistance & to countermine their Intentions, or to force theire Motions a cleane contrary way.

"The 9 was left out in ye original copy.

"Soe here yu have 9 figures represented, wch in Arithmetick make all numbers imaginable, soe by ye helpe of these Motions noe Manufacture but may be demonstrated exquisitely & demonstrably & with great ease & facility, and noe Conclusion in ye Mathematicks or Mechanicks, but may by these bee brought to passe in great perfection & to admiration. Yet as ye most excellent tooles cannot worke alone, nor any Cymeter is soe sharp as to cut without an arme to guide it, so without Knowledge, Art, & Ingenuitie, these are fruitlesse; but being set to work by one of noe more knowledge then myselfe am capable off, they will performe wt is here asserted & more than I could write from one end of ye yeare to the other."

the most sceptical may at length admit, that it may truly and clearly describe an effect easily produced by a well-known mechanical agent. "I can make," says the marquess in the sixth problem of this summary, "one pound raise an hundred as high as the one pound falls; and the one pound being taken off, the hundred and twelve pounds shall again descend, performing the entire effect of an hundred weight;—that is, I have *that force which nothing less than one hundred and twelve pounds can have in any other way.*" And he himself, as if aware of its apparent difficulty, calls it "an *incredible effect till seen,* but true as strange." It may be borne in remembrance, that he is describing some of the effects of steam; and by these the riddle, as we have before stated, can easily be explained: the solution shows us, that the noble inventor may have been describing a *high-pressure steam-engine,* whose *piston, weighing a pound, and attached to one end of a lever, raises one hundred and twelve pounds placed at the other extremity.*

From this passage there is so strong ground for the opinion, that he was acquainted with some mode of elevating a piston by steam, that we should hesitate to say, that Lord Worcester, in his "scantlings," described *any other* than a *high-pressure lever engine;* and this is still farther corroborated by the same interesting manuscript record, where this extraordinary man announces *another contrivance, which could only be practicable with a machine in this form,* and which may almost rival, in its importance to mankind, the invention of the steam-engine itself.—"By it," says the noble author, "I can make a vessel, of as reat burden as the river can bear, to go against

the stream, which the more rapid it is, the faster it shall advance, and the moveable part that works it, may be by one man still guided to take advantage of the stream, and yet to steer the boat to any point; and this engine is applicable to any vessel or boat whatsoever, without being therefore made on purpose, and worketh these effects,—*it roweth, it draweth, it driveth,* (if need be,) to pass London Bridge against the stream at low water, and a *boat laying at anchor, the engine may be used for loading or unloading.*" Thus this master spirit enumerates effects, which have been generally considered as first produced in our times by the application of steam power to navigation. It now in every quarter of the globe draweth, roweth, and driveth, magnificent vessels; but it yet remains to supersede by its use the labour of men in loading and unloading ships of their cargo, as suggested by Lord Worcester.

In illustration (for some particular purpose which is now unknown) of the powers of this "water-commanding engine," its inventor printed what he entitled, says Walpole, "An exact and true definition of the most stupenduous water-commanding machine, invented by the right honourable and deservedly to be praised and admired, Edward Somerset, Lord Marquess of Worcester."* This

* "MOST GRACIOUS SOVEREIGN.

"The same individual definition of my water work, which I formerly presumed to put into your royal hands, I again adventure to present to your majesty; praying your belief of it, as your majesty shall find it true, by comparing it with the real effect, which, if found punctually agreeing, vouchsafe not then to be apt hereafter to lend a believing eare to such persons, as malice causeth to detract from, or ignorance to slight what shall (though never so seemingly strange) be averred by

is a statement of the uses of his invention, and forms a thin quarto of twenty-two pages. In the library of the British Museum is preserved a large sheet, (without a date, and printed on one side only,) which appears to have been circulated by the marquess, and also to have been presented to King Charles.

"A stupenduous water-commanding engine, boundless for height and quantity, requiring no

me, who will never be convinced of a falsehood in word or deed towards your sacred majesty; before whom I shall ever speak, as in the presence of Almighty God, whose vicegerent on earth I deem you: and to your majesty's transcendent judgement I submit all, and will presume to subscribe myself,

Sir, *Your sacred majesties faithfully devoted, and passionately affected, useful, if cherished, subject and servant,*

"Worcester."

"*A stupenduous Water-commanding Engine, boundless for height or quantity, requiring no external, nor even additional help, or force to be set or continued in motion, but what intrinsecally is afforded from its own operation, nor yet the twentieth part thereof; and the Engine consisteth of the following particulars:—*

"A perfect counterpoise for what quantity soever of water.

"A perfect countervail for what height soever it is to be brought unto.

"A *primum mobile* commanding both height and quantity regulatorwise.

"A vicegerent or countervail supplying the place, and performing the full force of a man, wind, beast, or mill.

"A helm or stern, with bitt and reins, wherewith any childe may guide, order, and control the whole operation.

"A particular magazine for water, according to the intended quantity or height of water.

"An aquaduct, capable of any intended quantity or height of water.

"A place for the original fountain or even river to run into, and naturally of its own accord incorporate itself with the rising water, and at the very bottom of the said aquaduct, though never so big or high. *By Divine Providence and heavenly inspiration, this is my stupenduous Water-commanding Engine, boundless for height and quantity.*

external, or even additional, help or force to be set, or even continued in motion, but what intrinsically is afforded from its own operation, nor yet the twentieth part thereof; and the engine consisteth in the following particulars:—a *perfect counterpoise* for what quantity soever of water; a *perfect countervail* for what height soever it is to be brought unto; a *primum mobile*, commanding both height and quantity, regulatorwise; a *vicegerent*, or *countervail*, supplying the place, and performing the full force of man, wind, beast, or mill. A *helm*, or *stern*, with bit and reins, wherewith any child may guide, order, and control the whole operation. A *particular magazine* for water, according to the intended quantity or height of water. An *aqueduct* capable of any intended quantity or height of water. A *place for the original fountain or river to run into, and naturally, of its own accord, incorporate itself with the rising water*, and at the very bottom of the aqueduct, though never so big or high."

Whoesoever is master of weight, is master of force,
Whoesoever is master of water, is master of both.
And, consequently, to him, all forceable actions and atchievements are easie.

Exegi monumentum ære perennius,
Regalique situ pyramidum altius;
Quod non imber edax, non Aquilo impotens
Possit diruere, aut innumerabilis
Annorum series, et fuga temporum.
Non omnis moriar; multaque pars mei
Vitabit Libitinam. * * HORACE.
* * dum stabit Anglia.

Reader observe, this tells us how to keep
Our morning thoughts awake while others sleep:
'Tis art and nature's product scan'd by some:
Judge of it by th' effects; then give your doom.

To God alone be all praise, honour, and glory, for ever and ever. AMEN. "WORCESTER."

Every particular in this description illustrates those given in the "Century." The elasticity of the steam can be made to balance any quantity of water; it can perform what any other first mover can perform, and can be guided by a cock turned even by a child; the magazine of water follows as a matter of course; and the place for the original fountain to run into may have been the reservoir in which part of his mechanism was placed, or from which, more probably, it was conducted into the machine. This also, evidently, was not accomplished by what he called suction; for he expressly observes, that it did *not act* on this principle.

The two attempts which have been made to design a machine from the descriptions in the "scantlings" and "definition," have proceeded on the opinion, that the water-commanding engine was constructed *without a piston*. An apparatus similar to the figure II, will nearly fulfil all the conditions of the description on this principle, without introducing parts which are universally considered to belong to later inventors. A boiler, *x*, is connected to two *receivers*, *a*, *b*, by a pipe, *s*; the steam is admitted or shut off by a cock, *e*, from each vessel alternately; and by a pipe, *m*, containing two valves opening outwards from each receiver, they are connected with the rising or eduction pipe, *i*; another pipe, *n*, *u*, connects the cistern with the receivers, and the cock at *n* interrupts the communication between the cistern and each receiver at pleasure; by a hole in each receiver, capable of being closed in an air-tight manner, the air may be expelled as it accumulates in either.

When steam is generated in the boiler, *x*, it flows through the pipe, *s*, and passing into the receiver,

a, which has previously been filled with water, it presses upon its surface, and forces it through the pipe, *m*, and up the eduction pipe, *i*, by which it is conveyed to the required height and distance. When all the water has been expelled, the attendant turns the cock, *e*, and the steam flows into the opposite receiver, *b*, and at the same time he also turns the cock, *s*, and water flows from the cistern into the receiver, *a*; the steam from the boiler now pressing on the surface of the water in *b*, forces it up the pipe, *i*; and when it has expelled all that it contains, the cock, *e*, again shuts off the communication with the boiler and the receiver, *b*, and the vapour rushes again into *a*, and forces the water which has flowed into it up the pipe as before, and so on, alternately, as long as vapour rises from the water.

This mechanism must be considered as purely imaginary; it is probable that Lord Worcester's apparatus was as simple in arrangement and construction, as it *must* have been rude in workmanship. In fact, this mode of applying steam, which although considered as producing the engine in its simplest form, requires a greater degree of ingenuity to adapt the parts to practice, than those of a high-pressure piston engine, besides its principle being much less obvious; and on this account therefore, an engine, in which the steam moves a piston, is much more likely from its simplicity, and the manageable nature of its parts, to have been that whose properties and uses were enumerated by Lord Worcester.

Steam generated in the boiler, *x*, is admitted by a pipe, *a*, to press on the upper side of a piston, *c*; this depresses it, and raises the other end of the lever, to which may be attached a pump-rod. When the piston has reached the bottom

of the cylinder, a cock, *e*, admits the communication with the atmosphere and the upper side of the cylinder, and another cock opens a passage for the steam from the boiler to the under side of the piston, which raises it, and reverses the motion of the pump-rod.

In 1663, he succeeded in procuring an act of parliament to be passed, enabling himself and heirs, for ninety years thereafter, to receive the sole benefit, profit, and advantage resulting from the use of this invention. One-tenth part of all the profit which might be realized was to be appropriated, without abatement, to his majesty Charles II. and his successors; and so exclusive was the patent privilege, and so sanguine were its patrons, that those who counterfeited this water-commanding engine were to forfeit five pounds an hour, for every hour they should be found to have used the simulated mechanism without the consent and license of the Marquess of Worcester, or his assigns.*

The fact, however, of the marquess ever having given to the water-commanding engine any, except a *descriptive, existence*, is debateable ground with authors in mechanics; and on that account it may be considered to require some higher authority than mere inference, to decide the point of his having actually constructed an engine.

The references, it is admitted, are all drawn from the marquess's *own* account of his *own* invention, and which were addressed to the public in order to induce them to listen to his schemes, and to patronise them. As his pretensions were as high as his imagination was prolific and sanguine, some shade of suspicion may attach to

* Walpole's Royal Authors, vol. iii. p. 164.

them as being highly coloured, from a less unworthy motive than deception—the gratification of personal vanity. Yet, surely, even this will not be urged, when he is followed into his closet. In his address to the Deity, the phantoms of an overweening conceit could find no place; after his death, the following manuscript prayer was found among his lordship's papers:—

"The Lord Marquess of Worcester's ejaculatory and extemporary thanksgiving prayer, when first with his *corporal eyes he did see* finished a perfect trial of his water-commanding engine; delightful and useful to whomsoever hath in recommendation, either knowledge, profit, or pleasure.

"Oh! infinitely omnipotent God, whose mercies are fathomless, and whose knowledge is immense and inexhaustible, next to my creation and redemption, I render thee most humble thanks, from the very bottom of my heart and bowels, for thy vouchsafing me (the meanest in understanding) an insight in so great a secret of nature, beneficial to all mankind, as this my water-commanding engine. Suffer me not to be puffed up, O Lord, by the knowing of it and many more rare and unheard of, yea, unparalleled inventions, trials, and experiments; but humble my haughty heart, by the true knowledge of mine own ignorant, weak, and unworthy nature, prone to all evil. O most merciful Father, my creator, most compassionating Son, my redeemer, and holiest of Spirits, the sanctifier, three divine persons and one God, grant me a further concurring grace, with fortitude to take hold of thy goodness, to the end, that whatever I do, unanimously and courageously to serve my king and country, to disabuse, rectify, and convert my undeserved, yet wilfully incredulous enemies, to reimburse thankfully my creditors, to reimmune-

rate my benefactors, to reinhearten my distressed family, and with complacence to gratify my suffering and confiding friends, may, void of vanity and self-ends, be only directed to thy honour and glory everlasting."

Although at every period of his life he seems to have been deeply impressed with the feeling, that progress never was made in any thing by supine wishes and dilatory efforts, unremitting perseverance and assiduous industry were, in his case, to be of no avail in stemming the tide of adverse fortune; his wishes were written in sand; and in the prosecution of his philanthropic projects he was fated to experience not only the neglect of the public but the ingratitude of friends, without being convinced of the hopelessness of the attempt at introducing improvements beyond the comprehension and spirit of the age. As long as hope survived, and that ceased not until he "was summoned by the angel of death," he continued to prefer with vigour his claims to public attention and patronage.

After his death,* the marchioness, who seems to have been of a congenial spirit, and to have been actuated by no small share of her husband's enthusiasm, continued her exertions to introduce the water-commanding engine. The zeal with which she prosecuted her scheme, being considered unbecoming her sex, and derogatory to her quality, a Romish priest, who had some influence with

* The marquess died at London on the 4th of April, 1667, and his remains were carried in much state to Ragland church, and interred in the family cemetry. Heath examined the vault in 1795, and found there a plate which had been placed on the coffin, with the following inscription:—

Illustrissime Principis Edwardi Marchionis et Comitis Wigomiæ Comitis de Glamorgan, Baronis Herbert de Ragland. et qui obit apud Londini tertio die Aprilis A Dni. MDCLXVII.

her ladyship, was selected to expostulate on the impropriety of her conduct, and to convey to her the wishes and opinions of her friends. "All those," says the confessor, with no small boldness, "who wish you well, are grieved to see your ladyship to be already so much disturbed and weakened in your judgment, and in danger to lose the right use of your reason, if you do not timely endeavour to prevent it, by ceasing to go on with such high designs as you are upon, which I declare, on the faith of a priest, to be true. The cause of your present distemper, and of the aforesaid danger, is, doubtless, that your thoughts and imaginations are very much fixed on your title of Plantagenet, and of disposing of yourself for that great dignity by getting of great sums of money from the king to pay your deceased lord's debts, and enriching yourself *by the great machine, and the like*. Now, madam, how improper such undertakings are for your ladyship, and how impossible for you to effect them, or any of them, all your friends can tell you, if they please to discover the truth to you."

"The effects," continues the confessor, "that flow from hence are many; as the danger of losing your health and judgment, by such violent application of your fancies in such high designs and ambitious desires; the probability of offending Almighty God, and prejudicing your own soul thereby; the advantage you may thereby give to those who desire to make a prey of your fortune, and to raise themselves by ruining of you. I confess that the devil, to make his suggestions the more prevalent, doth make use of some motives that seem plausible, as of paying your lord's debts, of founding monasteries, and the like; and

that your ladyship hath the king's favour to carry on these designs." *

The great machine appears at this time to have been in existence; but it were idle to multiply instances from the marquess's personal history, or from that of his family. The first has been thought to savour of enthusiasm, and the latter might be ascribed, however unjustly, to the praiseworthy, but probably mistaken, gratitude of those whose affection might urge it as a duty to be tender of the reputation of an amiable relation or friend, even in matters which might be considered as those of his wanderings.

No such objection can, however, apply to the testimony of an eye-witness, and one who cannot be accused as speaking from either interest or friendship. The inspection was made two years after the death of the noble inventor; the account of it, written in a foreign tongue, lay hidden in a manuscript, deposited in a foreign library, for one hundred and fifty years after the machine itself, probably, ceased to be in existence; and we feel no small gratification in being the first to give it a place in the history of the steam-engine.

About the year 1656, Cosmo de Medicis, grand duke of Tuscany, sought respite and solace from unhappy family dissensions, by visiting the courts of foreign countries. Cosmo was accompanied by a retinue of men of letters and artists, for the purpose of recording those circumstances and scenes which during his journey might appear worthy of remembrance. A minute and circumstantial account of each day's occurrences was regularly entered into a journal by the grand duke's secretary. At Cosmo's return to Italy,

* The marchioness died in 1681.

this Diary was carefully deposited in the ducal library at Florence.

From its containing a variety of particulars respecting persons and places in England, it had become an object of considerable interest to those Englishmen who were aware of its existence. But it was not until 1818 that any part of its contents was disseminated by the press, when that portion of the manuscript volume which related to England was translated from the Italian, and published in a quarto volume.

In that translation, under the date of the 28th May, 1699, we have the following account of *one* of Lord Worcester's machines :—" His highness, that he might not lose the day uselessly, went again, after dinner, to the other side of the city, extending his excursion as far as Vauxhall, beyond the palace of the archbishop of Canterbury, to see an hydraulic machine, invented by my Lord Somerset, Marquess of Worcester. It raises water more than *forty geometrical feet*, by the power of *one man only*; and in a very short space of time *will draw up four vessels of water, through a tube or channel not more than a span in width*; on which account it is considered to be of greater service to the public, than the *other* machine near Somerset-house."

This therefore is superior in its operation to *another machine by a different mechanic, and applied to the same purpose.*

Now, in another part of the same Diary, it is stated, that " his highness went to see an hydraulic machine, raised upon a wooden tower, in the neighbourhood of Somerset-house, which is used for conveying the water of the river to the greatest part of the city. It is put in motion by *two* horses, which are continually going round; it not

being possibile that it should receive its movement from the current of the river, as in many other places where the rivers never vary in their course. But this is not the case with the Thames, owing to the tide, consequently the wheels which serve at the ebb, would not do their duty when the tide returns."

Nothing can be more satisfactory than this last notice; the water in the hydraulic machine at Vauxhall, by the most easy inference, was *not* elevated by a water-wheel, otherwise the grand duke would not have omitted to mention so striking a deviation from that at Somerset-house. The effect was equal to that of another worked by *two horses*; and a tyro in mechanics would, at first sight, say, that no combination of machinery could accomplish that work by one man, which it required the power of twelve men to do in another. From all the circumstances, therefore, it appears to us clear, that this great effect was produced by some sort of a steam-engine; the very identical "most stupenduous water-commanding engine;" the "semi-omnipotent engine;" the admirable and most forcible way to drive up water by fire; "the most stupenduous water-work in the whole world," which he humbly beseeched God to make him humble, as being its discoverer; and which, when he had gone to that "bourne from whence no traveller returns," his widow incurred the imputation of insanity for persisting to carry forwards. And well may we add, in his own language, that in our times it appears indeed "to have been produced by heavenly inspiration," and in its power, "boundless in height and quantity."

From the brevity of the notice in the grand duke's manuscript, it is probable he was ignorant

of its principle. It was too novel to be forgotten, had it been imparted to his highness. But this sort of concealment was the fashion of that time, as it is in some instances that of our own. Other coincidences between the descriptions of Cosmo's journal, and those in the "Century of Inventions," are truly remarkable. In both, the height of *forty feet* is stated to be the elevation to which the water is to be raised; in both the attendance of *one man* is mentioned; and *four vessels* of water through a tube or channel of not more than a span in width, being drawn up, is almost the same choice of words used in his celebrated sixty-eighth proposition. In fact, had the marquess been describing the engine himself, from a view of it in operation, without wishing to describe the principle of its operation, he could scarcely have used other terms, than those used in the journal of Cosmo of Medici.

Jean Hautefeuille, the son of a baker at Orleans, during his boyhood, gave indications of great mechanical genius; but the narrow circumstances of his family compelled him to follow the humble and laborious occupation of his father, until by an unexpected circumstance he was drawn from obscurity, and placed in a situation better fitted to his talents. The elder Hautefeuille supplied the household of the governor of the city with bread, at the time when the Duchess de Bouillon, being exiled to Orleans, resided in his family. The flattering terms in which the benevolent De Sourdis mentioned the ingenuity of the younger Hautefeuille, was followed by his introduction to the duchess. The pleasing manners of the youth attracted her regard; she took him into her family, which he never afterwards quitted, enabled him to study, on his entering the church

presented him with several benefices, and having contributed during her life every thing in her power to his advancement, at her death she testified the sincerity of her esteem by leaving the abbé a liberal pension. The patronage of the noble lady in this instance was meritoriously bestowed; and Hautefeuille became one of the most celebrated mechanics of the age; among other ingenious projects, in 1678, he propounded several curious and novel applications of heat, as a moving power. In one, he suggested that the vapour of *alchohol*, instead of water, should be used in such a manner that the liquid should evaporate and be condensed, "*tour à tour*," without being wasted; he also proposed small charges of gunpowder, instead of vapour from boiling water, and gave descriptions of three machines for this purpose. The first condensing the vapour and forming a vacuum, raised water by the pressure of the atmosphere; the second effected the same object, by the pressure of the vapour upon the water to be raised; and, in the third modification, the gunpowder vapour impressed an alternate motion on a piston, which he described as being adapted to execute a number of very varied operations.* Huyghens, in a memoir which he presented to the Academy of Sciences in 1680, mentions having long entertained the idea that the expansive force of gunpowder could be applied with advantage to other uses than fire-arms, or blasting rocks, to a portable and convenient mechanical power; but his modification is less perfect than the third one by Hautefeuille,

* *Pendule Perpétuelle*, avec la manière d'élever d'eau par le moyen de la poudre à canon. p. 16. Paris, 1678. *Réflexions* sur quelques machines à élever les eaux. p. 9. Paris, 1682.

and as he advances no proof that he ever put it in practice, it may be dismissed in as brief a manner as he announces it.

The foundation of the mechanical superiority of England may be said to have been laid in the time of Charles I. The reign of Charles II. was one of the most favourable periods that had been in England for the advancement of its arts; and it detracts little from the merit of the "merry monarch," whether his patronage followed, or led the taste of his court into these channels. "His majesty was, however, much devoted to the study of mechanics, mathematics, natural history, and chymistry, on which account he sent for a skilful professor of these arts from France, and erected for him, in St. James's Park, a suitable building for carrying on his operations and experiments." The king took particular pleasure in experiments relating to navigation, of which he had a very accurate knowledge; "and paid great attention to finding out what sorts of wood require the least depth of water to float them, and what shapes are the best adapted for cutting the water and making good sailers;" and his brother's (the Duke of York) taste was strongly turned towards the same pursuits. The well-known Sir Robert Moray had the control of the king's laboratory, and the office of "master of mechanics" was conferred on Sir Samuel Morland,* an ingenious practical

* Sir Samuel was the son of the Rev. Thomas Morland rector of Sulhamstead, in Berkshire, and was born abou 1625. From Winchester school he was sent to Cambridge where he devoted himself to the study of mathematics. In 1653 he accompanied Whitelocke on the famous embassy to the Queen of Sweden; and was afterwards sent by Cromwell to the Duke of Savoy, regarding his expulsion of the Waldenses, a business which he is said to have conducted with great address. He remained some time at Geneva, and after his

mechanic, and was often employed by the king in that capacity.

return he wrote a "History of the Evangelical Churches of the Vallies of Piedmont," with numerous cuts. At his return he received the thanks of a select-committee appointed to inspect his transactions. He was now high in the confidence of Thurloe, secretary to Cromwell, and admitted into the most intimate affairs of state; but overhearing the discussion of a plot to assassinate Charles II., he, fearing the king's blood might be laid to his charge another day, disclosed it to that monarch at Breda. He was then in affluence, having, as he said, "a house well furnished, an establishment of servants, a coach, and 1000*l.* per annum, and a beautiful young woman to his wife for a companion." He was created a baronet in 1660, and master of mechanics to the king; and held several pensions as remunerations for various experiments which had involved him in pecuniary embarrassments: "these experiments," he said, "had pleased the king's fancy, but when he spent 500 or 1000 pounds upon them, he received sometimes but half, or a third of what he had expended." He married a second wife, who pretended to be an heiress of 20,000 pounds, but was a beggar, and when she turned out a strumpet he divorced her. Two years before King Charles's death he was sent into France about the king's water-works, but here he again lost more than he gained. Water engines employed much of his attention, and in 1774, in the Journals of the House of Commons, is a notice of a bill to enable him to enjoy the sole benefit of certain pumps and water engines invented by him. He was, probably, a very gay man in his youth, for he acknowledges having been excommunicated. He invented the speaking trumpet, a fire engine, a capstan to heave anchors, and two arithmetical machines, of which he published a description.

Sir Samuel, in 1675, obtained a lease of Vauxhall-house, (now a distillery,) made it his residence, and considerably improved the premises, every part of which showed the invention of the owner. The side-table in the dining-room was supplied with a large fountain, and the glasses stood under little streams of water. His coach had a moveable kitchen, with clock-work machinery, with which he could make soup, broil steaks, or roast a joint of meat. About 1684 he bought a house at Hammersmith, near London, where he died in January, 1696, and was buried in Fulham church.

He gave a pump and well adjoining his house for the use of the public, which was thus recorded upon a tablet fixed in the wall: "Sir Samuel Morland's well, the use of which he freely

In 1675, he obtained a patent for a certain powerful machine to raise water. By the strength of eight men it forced water from the Thames to the top of Windsor-castle, and sixty feet higher, in a continual stream, at the rate of sixty barrels an hour. This was repeated, in 1681, before the king, queen, and court, at which time his majesty presented his *magister mechanorum* with a medal, having his effigy set round with diamonds.

In 1681, he was sent to France on business connected with his majesty's water-works, and during his residence in Paris he repeated the experiments to raise water, and erected several pumps, on his peculiar construction, in the houses of his friends: he also exhibited some models in action before King Louis, at St. Germains. These exhibitions, it has been stated, were given for the purpose of obtaining that patronage for his invention from the court of France, which he had failed in securing from his own.*

gives to all persons, hoping that none who shall come after him will adventure to incur God's displeasure, by denying a cup of cold water, (provided at another's cost, and not their own,) to either stranger, neighbour, passenger, or poor thirsty beggar. July 3, 1695." A malediction rests on some head, for the well has disappeared.

* This inference has, probably, received currency from the following statement by Dr. Hutton. "To Sir Samuel also, it appears, is due the first account of the steam-engine; on which subject he wrote a book, in which he not only showed the practicability of the plan, but even went so far as to calculate the powers of the different cylinders. The author dates his invention in 1682, consequently seventeen years prior to Savery's patent. It was presented to the French king in 1683, at which time experiments were actually shown at St. Germains. As Sir Samuel held places under Charles II., *we must naturally conclude, that he would not have gone over to France, to offer his invention to Louis XIV., had he not found it slighted at home.* The project seems to have remained obscure in both countries till 1699, when Savery, *who probably knew more of Morland's invention than he owned*, obtained a

But as he nowhere mentions any thing of the sort, it is probable he had neither failed at home, nor solicited for encouragement abroad. In fact, his mission was to examine the machine at Marli, which Rannequin, that year, had put in motion, to supply the palace of Versailles with water; and Sir Samuel's exhibition of his cyclo-elliptique pump was made as much in the view of its being a novel exhibition, then particularly interesting to the French court, as with an hope of being able to introduce the use of his apparatus into France, and to secure to himself a monopoly of its profit.

These experiments, however, have been adduced as evidences of his having, at the same period, shown to the French king the method of raising water by means of fire. But no account of any such experiment is known to be in existence, or any expression which, even by inference, can be supposed to warrant such assumption. His book,* printed in 1685, on elevating water by all sorts of machines, does not contain a word on the subject. From that work, it might, probably, appear he was not unacquainted with the use of steam as a substitute for animal power; but even this can only be inferred after a very liberal construction of a dubious expression. Enumerating various moving forces, he mentions that to be

patent, and, in the very same year, *M. Amontons proposed something similar* to the French academy as his *own!*" *Mathematical Dictionary*, vol. ii. p. 71. 1822.

* Elévation des Eaux par toute Sorte de Machines pour le bien public, par le Chevalier *Morland*. Jombert. A Paris. 1685. The copies generally appear without a date, from the bookseller's name being pasted over it, the title-page having been printed without this appendage.

"Selon la force mouvante donnée, soit des rivières ou du vent, soit des chevaux ou des hommes, soit enfin du feu ordinaire ou de celuy de la poudre à canon."

had from the current of rivers, from the action of wind, the force of men or horses, *or even of a common fire*, or from gunpowder.

It may be true, that, in 1683, he presented to the King of France a small and splendidly written book,* which, among other matters, contains some calculations of the size of cylinders to raise, by steam, a certain quantity of water a certain height in a minute; and he also gives an approximation towards the expansion of a quantity of water into vapour, very remarkable from its correctness, considering the early stage of the inquiry. But we are left in total ignorance with regard to his manner of experimenting.

The manuscript volume which is preserved in the British Museum, is also said to have been that presented to the King of France: it may have been so. The first part of this little book is most exquisitely written, each page is beautifully ornamented with a gold border, gold letters, and words in different coloured inks, and every way worthy not only of being presented to a king, but to be admired by the most tasteful monarch for its delicacy and elegance: but the latter part of it—all that relating to the experiments on steam, (which is given entire in the note,†) is in a

* ELEVATION des Eaux par toute Sorte de Machines réduite à la Mesure au Poids et à la Balance, présentée à SA MAJESTE *Très Chrétienne* par le Chevalier MORLAND, Gentilhomme Ordinaire de la Chambre Privée, et Maistre de *Méchaniques* du ROY de la GRANDE BRETAIGNE, 1683.

† Les Principes de la Nouvelle Force de Feu inventée par le Chevalier *Morland*, l'An 1682, et présentée à Sa MAJESTE *Très* CHRETIENNE, 1683. L'Eau estant évaporée par la force de feu, ces vapeurs demandent incontinent un plus grand d'espace (environ deux mille fois) que l'eau n'occupoit auparavant, et plus tost que d'être toujours emprisonnées, feroient crever une pièce de canon. Mais estant bien gouvernées selon les règles de la statique, et par science réduites à la mesure

very vulgar taste, coarsely written, without ornaments of any kind, and altogether at variance with the other division of this elegant volume, and on this account most unlikely ever to have formed a part of that which, from its admirable finish,

au poids et à la balance, alors elles portent paisiblement leurs fardeaux (comme de bons chevaux) et ainsy seroient elles du grand usage au gendre humain, particulièrement pour l'élévation des eaux, selon *la Table suivante*, qui marque les nombres des livres qui pourront être 1200 fois par heure, à 6 pouces de louée par des cylindres à moitié remplies d'eau aussi bien que les divers diamètres et profondeurs des dits cylindres.

TABLE.

DES CYLINDRES.		DES LIVRES.
Diam. en Pieds.	Profondeur en Pieds.	Livres du Poids pour être levées.
1		
2		
3		
4		
5		
6		
[illegible] diamètre 6 pieds et 12 pieds de profon.	1	
	2	
	3	
	4	
	5	
	6	
	7	
	8	
	9	
	10	
	20	
	30	
	40	
	50	
	60	
	70	
	80	
	90	

was, probably, placed in the hands of King Louis.

From this, however, he appears also to have been acquainted with the experiment in the "Century of Inventions," of bursting a cannon by steam. He further describes vapour, when governed, to beat itself quietly under the harness like good horses; a turn of expression not very different from the Marquess of Worcester's. These coincidences would almost, in the absence of every other fact, establish a knowledge of his predecessor's experiments, even supposing that the water-commanding-engine itself, which was employed for a public purpose, and in action a few years before, adjoining the garden wall of Sir Samuel's house at Vauxhall, was unknown to him.

About the middle of the seventeenth century, a pamphlet* was published at London, which contains, in the form of a letter to *Hartlib*, the celebrated farmer, an enumeration of the uses to which a machine could be applied, which the anonymous author states he had invented. "Whereas, by the blessing of God, who only is the giver of every good and perfect gift, while I was searching after that which many, far before me in all humane learning, have sought but not yet found, viz. a perpetual motion, or a lessening the distance between strength and time; though I say, not that I have fully obtained the thing itself, yet I have advanced so near it, that already I can, with the strength or helpe of four men, do any

* P. S. *Invention of Engines of Motion lately brought to perfection*; "whereby may be despatched any work now done in England, or elsewhere, (especially works that require strength and swiftness,) either by wind, water, cattel, or men, and that with better accommodation and more profit than by any thing hitherto known and used." London, 1651.

work which is done in England, whether by winde, water, or horses, as the grinding of wheate, rape, or raising of water; not by any power or wisdome of mine own, but by God's assistance, (and, I humbly hope, after a sorte,) immediate direction, I have been guided in that search to tread in another pathe, than ever any other man, that I can hear or reade of, did treade before me; yet, with so good success, that *I have already erected one little engine, or great model, at Lambeth*, able to give sufficient demonstration to either artist or other person, that my invention is useful and beneficial, (let others say upon proof how much more,) as any other way of working hitherto known or used." And he proceeds to give "a list of the uses or applications for which these engines are fit, for it is very difficult, if not impossible, to name them all at the same time. To grind malt, or hard corne; to grind seed for the making of oyle; to grind colours for potters, painters, or glasse-houses; to grind barke for tanners; to grind woods for dyers; to grind spices, or snuffe, tobacco; to grind brick, tile, earth, or stones, for plaster; to grind sugar-canes; to draw up coales, stones, ure, or the like, or materials for great and high buildings; to draw wyre; to draw water from mines, meers, or fens; to draw water to serve cities, townes, castles; and to draw water to flood dry grounds, or to water grounds; *to draw or hale ships, boates, &c. up rivers against the streame; to draw carts, wagons, &c. as fast without cattel; to draw the plough without cattel to the same despatch if need be;* to brake hempe, flax, &c.; to beat hempe, flax, &c.; *to weigh anchors with less trouble and sooner;* to spin cordage, or cables; to bolt meale faster and fine; to saw stone and timber; to polish any stones or mettals; to turne any great

works in wood, stone, mettals, &c., that could hardly be done before; to file much cheaper in all great works; to bore wood, stone, mettals; to thrashe corne, if need be; to winnow corne at all times, better, cheaper, &c. For paper mills, thread mills, iron mills, plate mills; *cum multis aliis.*"

If this extraordinary "engine of motion" was not some kind of a steam-engine, the knowledge of an equally plastic and powerful motive agent has been utterly lost. And if the author of this anonymous tract was not the Marquess of Worcester, some equally great mechanical genius existed in his time, whose labours were turned to the same point; who used the same modes of expression when describing them; who applied his invention to the same purposes, but whose very name has perished.

CHAPTER THIRD.

"MAY I ENCOURAGE YOU, DEAR SIR, NOT TO GROW WEARY IN YOUR MIND, NOTWITHSTANDING THE INFINITE CORRUPTION YOU MEET IN THE WAYES OF MEN TO STOP YOUR COURSE, BUT TO CONTINUE, AS HITHERTO, TO CAST YOUR BREAD UPON MANY WATERS, FOR ASSUREDLY OF THIS YOU WILL REAP AN ABUNDANT HARVEST IN DUE TIME IF YOU FAINT NOT."—*Anon.*

THE year previous to that in which Sir Samuel Morland exhibited his experiments at St. Germains, Dr. Denys Papin, an ingenious Frenchman, had invented a mode of softening bones by enclosing them in a boiler, constructed to generate steam of a high temperature. By this contrivance he said he extracted "marrowy nourishing juices from bones, that the most thrifte housewife declared had been abandoned as but poore prey by ye hungry dogs," and beef, "*even the oldest and hardest cow-beef,*" and other meats, whose horny and shrivelled fibres baffled the skill of the most experienced cooks to prepare for mastication, with common boilers, when "done" in his digester, came forth tender, succulent, and pulpy; in fact, so extraordinary was the effect of this "high-pressure steam" process, that the coarsest bones and most obdurate gristle glided gently into the stomach, in the attractive shapes of savoury soups and glutinous jellies;* and there is little doubt

* "I took beef bones that had never been boiled, but kept dry a long time, and of the hardest part of the leg; these being put into a little glass pot, with water, I included in the engine,

but that, at one time, Papin was so proud of the power of the new utensil that he had put into the hands of the *coquus*, that flesh was considered by him to be little better than an excrescence with which nature had concealed and encumbered the virtues of bone and cartilage.

The digesting process being found accompanied with some degree of danger, in the account of his "engine," which he printed in 1681, when he resided at London, to guard against the fatal effects which would follow the bursting of the boiler, he added a contrivance, which is now well known by the name of the *safety valve*, an opening made in the cover or roof of the boiler and closed by a lever, pressing a movable weight on the orifice.

"You must have a little pipe open at both ends, as *e*, this being soldered to a hole in the cover, *a*, is to be stopt at the top with a little valve exactly ground to it, and fitted also with a paper between, this must be kept down with an iron rod, one end of which must be put into an iron staple, *r*, fastened to the bars, and the other end kept down by a weight, *o*, to be hung upon it nearer or further from the valve, according as you would keep it less or more strongly down upon the end of the pipe to resist the less or greater pressure from within, much after the manner as a weight is hung upon an ordinary Roman balance or steelyard. To prevent the *drying of the paper* of this valve, a *little pipe* is tied round

having prest the fire until the drop of water would dry away in 8 seconds, or 10 pressures, I found very good jelly in my pot, without taste or colour, like hartshorn jelly; and having seasoned it with sugar and juice of lemon, I did eat it with as much pleasure, and found it a stomachick, as if it had been jelly of hartshorn." *New Digester for Softening Bones*, p. 22.

about with hemp and thrust down into the pipe, so that one end reacheth pretty far into the water in the engine, whence it comes to pass, that if some of the said water be lost, the inward pressure will, nevertheless, drive up water through the pipe, *e*, against the valve and make it more exact."*

The valve-pipe must be but slender, that it may be kept shut by a little weight, and his pipe was two-fifths of an inch in diameter; the weight at the end of the rod was a pound, placed twelve inches from the valve, and that was one inch from its fulcrum; and, therefore, when one pound weight was hanging at the end of the lever, and water gets out of the valve, the inward pressure is about eight times stronger than the ordinary pressure; and by increasing or lessening the weight, or by removing it from one place to another, one may always know near enough how strong the inward pressure is." This lever being merely inserted in a hole made in a projecting rim, it was with difficulty kept in its proper position, and the orifice of the pipe was by this means often unclosed,

* P. 6, *ibid.*

"Having found some difference, both for the quantity, and for the readiness in drawing jellies from several bodies, I believe there might be found a difference in several other properties of them; and seeing our bodies are but congealed liquors, it is likely that if people would go on with this trial, and draw jellies from several parts of the same animal, and from several animals of the same kind, but of different ages, and from several kinds of animals that live a great deal longer one than another, as from hares and rabbits; and then if they would compare all the several properties of these jellies with one another, it is likely, I say, that it would be a great help towards making a better theory than hitherto we have about the causes of the lastingness of our life, and such a theory would, it may be, prove of more consequence than many people are apt to believe." P. 28, *ibid.* Papin practised with success as a physician.

when this happened it invariably was found that "the meat was spoiled." A Dr. King, "for greater security and conveniency, caused the lever to be fitted with a joint, so that it must always fall upon the pipe, and there is no danger that the valve (or stopper) may slip off and spoil the operation."*

"But an engine which was made for the laboratory of his majesty, Charles II., of blessed memory, has the advantage to have no hole to the cover, which in the first engines caused some trouble, besides some danger,"† which probably arose from the boiling water being forced upwards; but even that was preferable to the danger in the king's engine of the cook being blown to pieces by the bursting of the boiler, instead of being scalded, as in the first apparatus. "To know," continues Papin, "the degree of heat in this boiler, instead of a thermometer I use another way, very easie, and yet exact enough for all my uses. I hang a weight to a thread about three feet long, so that every swing makes a second, and I let fall a drop of water into a little cavity, made for that purpose at the top of it, (the roof of the boiler,) and I tell how many times the hanging weight will move to and fro before the drop of water is quite evaporated; and I take care that the place where I put the drop may be clean, because a little grease will considerably hinder its evaporating."‡

* Continuation of the New Digester, p. 53, 1687.

† P. 3, *ibid.*

‡ The drop of water drying up in five seconds indicated a degree of heat equal to ten pressures; in three seconds equal to nine pressures; he had built no furnaces for his boiler, but always had set it "in a chimney corner, and put the fire between the chimney and the engine." Dr. King caused a brick furnace to be built on purpose, thinking that would lessen the expense for coals. "But I found, contrary to my expectation, that the expense is much greater in his furnace; the

In 1685, the same philosopher exhibited a model of a machine for raising water, "and having seen it practised several times, that after the discovery of some new problem the inventor propounds it as a riddle, to stir up those that are ingenious in the same kind of learning, and make them find sometimes better things than what is propounded." Papin thought "he might do the same with his way for raising water, which he thought surely to be new, since it is not used, in considerable occasions, where it might be of great advantage."*

The solutions which were given by three persons who made the attempt, not fulfilling the conditions

reason of which probably is, because in his furnace the coals did not at all touch the engine, but remained a little distance below; as in ordinary sand furnaces, the coals do not touch the pot, but in my chimney the *coals touch* the engine almost all along, and thereby may the better heat it. It is, therefore, likely that it would be better to build furnaces so as to have the coals touch the engine all along one side." *Continuation of the New Digester*, p. 53.

He found "that the quantity of coals required to boil beef was nearly two-sevenths greater than that required to boil mutton:" his valves were made tight with paper—leather melted; sometimes he softened the biggest bone of a leg of beef without *spoiling* the meat. With steam of nine pressures he boiled "a piece of a breast of mutton with six ounces of coals;" a breast of beef under nine pressures was cooked with six and a quarter ounces: from his experiments he concluded, "that the more briskly we press the fire, the more effect it produceth with the same quantity of coals. The greater the inward pressure is, the greater effect is produced by the same heat in the same time; that it is near the same to press the fire with four and a half ounces of coals, so as to dry away a drop of water in ten seconds, and then let the fire go out of itself; or to press the fire with six or seven ounces, and then take it all off as soon as a drop of water dries in three seconds: the greater the inward pressure is, the less quantity of coals is required to give a certain degree of heat."

* Philosophical Transactions, vol. xv. p. 1093.

of his problem, in a few months afterwards he gave a description of his model, from which it appeared, that the water was raised by rarefying the air in the vessel into which it was impelled by the pressure of the atmosphere on the water in the cistern. The mode by which he rarefied the air was carefully concealed. In two of the solutions the same effect was produced by condensing it.

Thus far the scheme may be considered an ingenious trick; yet an useful air was given to his proposition by showing how a series of exhausting vessels might be connected so as to raise water from considerable depths;* and a suggestion for communicating motion by means of air to a great distance, which grew out of a discussion respecting its practicability, was conceived in an original and philosophical spirit. Suppose, for example, that it was required to raise water out of a mine, and that there was no river to turn a wheel to move the pumps nearer than a mile. Papin proposed to place two cylinders fitted with pistons near the water-wheel, and other two at the mouth of the mine; these were to be connected by a pipe. The action of the pistons moved by the wheel compressing the air in the cylinder and in the pipes throughout its whole length, Papin thought, that when the pistons at the one end were depressed by the communication of pressure, those at the other end would be elevated. But although the pumps, moved by the water-wheel, condensed the air, the pistons at the mine stood still. And the failure arose from a property of air, which, however familiar to Papin as a mechanical philosopher, was overlooked in his apparatus. The air itself was a very compress-

* Phil. Trans. vol. xv. p. 1274.

ible body, and in his mechanism it was not compressed sufficiently to offer such a resistance to further condensation, as was necessary to move so great a weight as that placed on the pumps of a mine.* Of two methods of remedying this defect, the one which happened to occur to Papin made his machine impracticable; the length which he found was required for his compressing cylinder was altogether preposterous.

Great as his reputation was in England, he failed in getting patrons to give a trial to his apparatus. But when he returned to France, and after he was driven from it by the revocation of the edict of Nantes, and had settled, in 1687, at Marpurg, in Germany, he was employed by some persons of large fortune to erect machines on this principle at Auvergne, and in Westphalia, to drain mines. The result had been predicted by Dr. Robert Hooke and others; the failure was complete. It was in vain that he attempted to get over the difficulty by increasing the capacity of the cylinders and diminishing that of the connecting pipe, the hopes of, by this means, keeping his cylinders of a moderate size were still to be disappointed. He now reverted, in part, to his first idea, constructing the pistons with valves and cocks similar to those of an air-pump, and instead of compressing the air in the cylinders, he formed a vacuum throughout the entire apparatus by the action of the water-wheel, in order that, by exhausting the cylinders under the pistons near the mine,† the pressure of the atmosphere should

* Nouvellès de République des Lettres, December, 1686. A Mons. Nuis urged some objections to Papin's scheme, which were answered in the Phil. Trans. No. 186, p. 263; from this it appears that his vacuum was equal to a pressure of twelve feet of water.

† Recueil de diverse pièces touchant quelques nouvelles

act to impel them downwards, and thus produce the required motion. His modification of the apparatus to accomplish this object may be shortly described.

The pistons at the mouth of the mine were attached to ropes, which were wrapped several times round an axle, or horizontal shaft, in opposite directions, so that when the one was coiling and drawing up its piston, the other was unwinding and allowing the other to descend. On this shaft a large wheel was also fixed, having a cord on its circumference carrying a bucket at each end, which alternately rose and descended as the piston-ropes were wound or uncoiled. The pistons near the water-wheel were attached to its axle in a similar manner, and arranged so, that when one piston was at the bottom, another was at the top of its respective cylinder; a single pipe formed a communication with the two sets of cylinders, branching at its termination to each cylinder, and having a *double passaged or fourway cock* at their junction with the conveyance pipe, to admit the air, and to shut it off from beneath each piston alternately.

By the motion of the water-wheel a vacuum was produced in the cylinders under the pistons and in the conveyance pipe; that piston near the mine cylinder, which was at the top of its vessel, having a communication with the connecting pipe, and the air being withdrawn from beneath it, was pressed downward by the atmosphere, this moving the axle drew the other piston upwards, the air being admitted under it at the instant it was shut off from the other; the cock is now turned; a communication is opened with the

machines et autres sujets philosophiques, par M. D. Papin, Dr. en Méd. A Cassel. 1695.

vacuum and the other piston which is depressed; and the air is at the same instant admitted beneath that which has just been impelled into its cylinder.

Papin proposed, by this most ingenious scheme, to transmit the power of the water-wheels, driven by the Seine, to work pumps, instead of the operose and clumsy methods which then so greatly excited the admiration of the vulgar at Marli. Still this was found to be useless in practice, from the extreme difficulty of procuring and preserving a perfect vacuum in the apparatus, and also from the exceeding tediousness of the process.* It is, however, due to the ingenious contriver to observe, that this idea has been considered to be one of great practical value; and an accomplished modern mechanic suggests, that the *only* addition wanting to his apparatus, to make it usefully efficient, is a receiver, or air chamber, near the cylinders, to be kept exhausted by the pumps; and this being of sufficient capacity the air will rush into it, and be taken away from beneath the piston the instant the cock is opened, whereas, without it, it would be drawn off more slowly by the pumps; but if the conveyance be made of large dimensions, it will effect the same end completely. Papin lessened the pipe.

The instantaneous combustion of gunpowder had been pointed out by Hautefeuille as offering a ready means of producing a power to elevate a piston; and stimulated by the thought of its being more noble and praiseworthy to show how to apply gunpowder to aid man in his labour, than to teach its application to machines used for his destruction, Papin conceived, that a *speedy vacuum* could also be formed by condensing its vapour;

* Recueil, p. 53.

but notwithstanding all his ingenuity, a fifth, and sometimes a greater proportion of the air remained in the cylinder, so that instead of a piston of a given size raising, as it ought to have done, upwards of three hundred pounds weight, it seldom elevated even so much as one hundred and fifty.*

In this state his projects remained until 1695, when Papin published a collection of essays descriptive of these and some other projects.

In a letter to the Comte de Sintzendorff, who had applied to him for his advice as to the best mode of draining some mines, after enumerating these projects, he abandons them as liable to insuperable objections. But he goes on to say, that he believes it would not be difficult to make a machine which, possessing the same arrangement of parts, and acting on the same principle, would accomplish the purpose the Comte de Sintzendorff had in contemplation. For as water possesses the property of being converted by heat into vapour, which possesses the same elasticity as air, and afterwards may be so completely recondensed by cold, that no part of its elastic power shall remain; therefore, by means of heat, and a small quantity of water, he could make that perfect vacuum, which he in vain attempted to produce by igniting gunpowder and condensing its vapour.

The scheme to which he gave the preference is very simple. A cylinder, fig. 1, made air-tight at the bottom, is fitted also with an air-tight piston, *d*. The stem of the piston goes through the cover of the cylinder. A lever, *n*, turning on a hinge, is fastened to the top, and a spring acts so as to press it into a notch in the piston rod, when

* Acta Eruditorum, p. 498. 1688. Papin gives a figure of his gunpowder cylinder, in tab. x. *Recueil*, p. 53.

it comes above the cover. A small pipe, *e*, is inserted through the cover of the cylinder, and also through the piston, and firmly closed at the upper end.

The stopper of the small pipe being taken out, the piston is then easily moved to the bottom of the cylinder. A small quantity of water is introduced through it beneath the piston, and it is again closed. The cylinder is now placed over a fire; steam of a high temperature is quickly produced, which forces the piston to the top of the cylinder, when the lever is immediately pressed by the spring into the notch in the piston-rod, which retains it in that position. The fire being withdrawn from the bottom, the air cools the apparatus, which condenses the steam, and a vacuum is thus formed beneath the piston. The lever being then disengaged from the notch, the pressure of the atmosphere impels the piston with a great force to the bottom of the cylinder. A fresh charge of water may again be introduced by the small pipe; when the fire is applied to the cylinder the piston will ascend a second time; and after a vacuum is formed by the cooling of the cylinder, it will be impelled downwards, as before, by the pressure of the atmosphere, and this alternate motion may be continued and prolonged at pleasure.

In our ignorance of Lord Worcester's mode, this may be considered the most important and masterly attempt that had yet been made to employ the elasticity of steam as a motive power; and it cannot but be a matter of regret, that its persevering and ingenious author should abandon his pursuit at the moment he had laid the foundation of the splendid mechanism of the lever engine, and had in his grasp a brilliant reward for a life of labour.

The simplicity of his experiment is not the least of its merit; and although the moving of the fire from and to the cylinder would now be reckoned as inartificial as it would be found inconvenient in practice, we should recollect that it was intended by its author as a rough experiment only to illustrate a principle.

It is still, however, very remarkable, that the condensation was always produced by cooling the cylinder by air; *artificial* means of refrigeration have never yet been suggested. Decaus condensed the steam in the ball by air; Hautefeuille followed the same plan; Lord Worcester has left us no observations upon it; and we are ignorant of Sir Samuel Morland's method. Papin's claim will not therefore be to the mode of producing steam in a cylinder, and raising a piston by its elasticity, for Hautefeuille did this; and so also, we conceive, did Lord Worcester, in the same way as that now practised in high-pressure engines; but for combining the force of steam to raise the piston, and forming a vacuum under it by condensing the vapour, thus bringing the atmospheric pressure to aid the effect of his apparatus. He asserts from experience, that an ordinary fire produced as much steam in a *minute* as was sufficient to elevate the piston in the cylinder with a force equal to the pressure of the atmosphere; by proportioning the fire, large cylinders, in his opinion, could be heated with almost greater facility than small ones.

The mode proposed by Papin, of withdrawing the cylinders from the fire, required that these vessels should be made as light as possible:* and the doctor set his speculation afloat, when he conceived that a cylinder might be made which

* P. 55, *ibid.*

should weigh not more than forty pounds, and yet be strong enough to contain a piston which would elevate a weight, equal to two thousand pounds, to a height of four feet.

Neither did it escape his penetration, that although in many situations steam could be used as a motive power, at a much smaller expense than animal labour, yet even in the most favourable case the consumption of fuel to form this vacuum must be enormous, and be attended with a great outlay. He had also observed, that this was partly occasioned by the imperfect combustion of the fuel itself, which was used in the furnace: and he proposed to diminish the waste by a different arrangement of the fire-place. In the usual construction coals are laid on a grate, over which is placed the boiler, and the air which "feeds the fire" *rises* through the fuel. Papin reversed this operation. He laid the coals on a grate, *a*, and the chimney, *b*, descended, and then rose in the manner of the two legs of a bent syphon; in the opposite end of which, *c*, was placed the steam cylinder. The portion of this syphon, which ascended, and which contained the cylinder, was longer than that containing the grate: the coals were spread on the grate in the common manner; wood was laid on the surface of the coals, this was inflamed, and a current of air was forced *downwards* upon the partially ignited materials; from the difference in the length of the two legs of the syphon, the descending current thus produced was continued; the materials were completely consumed, and instead of the fuel escaping in the form of a heavy and offensive vapour, the gases emitted were nearly imperceptible.

By using this construction of furnace the economy of fuel is prodigious; the *intense heat* which

is generated being its only objection; for it was found by succeeding experimenters, that the materials which composed the fire-place, as well as the fuel, disappeared before the energy of the "little volcano."

Papin apparently not being aware that this current would continue in the descending direction, hinted the advantage to be derived from forcing the air upon the fuel; and hazarded the conjecture, that a double velocity being given to it the heat produced should be *four* times greater.*

This fine arrangement and combination of parts was equalled by the purposes to which the ingenious Frenchman suggested it might be applied. The object he had first in view was the draining of mines; he said it might also *throw bombs;* and above all, that it might *propel a vessel against the wind,* and supersede the labour of rowers and galley-slaves in ports and havens; and thus allowing these persons to be employed on their proper element, the sea, instead of reposing the greater part of their time in port or on shore.†

In discussing the advantages of his mechanism over human power in maritime movements, the mechanical difficulties which were to be overcome before his project could be practicable were observed but to be ingeniously obviated. He was quite aware that the rectilineal movement of the piston in his cylinder could not be effectively applied to a mechanism like a common oar.

During his residence in England he had witnessed an interesting experiment made on the Thames, in which a boat, constructed from the design of the Prince Palatine Robert, was fitted with

* P. 63, *ibid.* † P. 51, *ibid.*

revolving oars, or paddles attached to the two ends of a long axle going across the boat, and which received its motion from a trundle working in a wheel turned round by horses. The velocity with which this horse-boat was impelled was so great, that it left the king's barge, manned with sixteen rowers, far astern in the race of trial.*

* The use of wheels for oars is very ancient. In some very ancient MSS. extant in the King of France's library, it is said the boats, by which the Roman army under Claudius Caudex was transported into Sicily, were propelled by wheels moved by oxen. And in many old military treatises the substitution of wheels for oars is mentioned.

Robert Valturius gives a view of two gallies moved by *wheels* instead of oars: the first diagram shows *five* wheels on each side of the vessel; each pair are connected by a separate axle running across the boat, this axle is formed like a crank in the middle of its length, and the five axles are connected together by a rod, or a rope, so that all their movements are simultaneous. The second diagram has one wheel at each side of the galley; these are also connected by an axle running across the boat, as shown in figure: he gives no details, but he merely mentions, that the velocity of these boats will be greater than if they were propelled by oars. *De Re Militari*, lib. xi. p. 2. Veronæ, 1472.

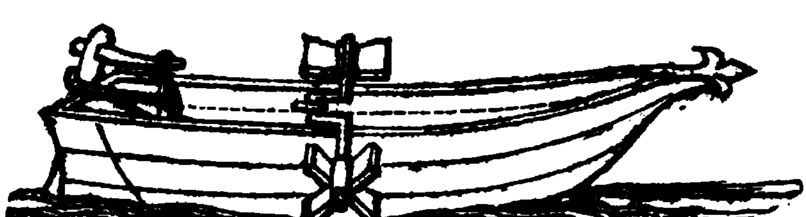
Pancirollus, a celebrated professor at Padua, in 1587, saw an ancient bas-relief, which represented a galley with three wheels on each side of a boat turned by three pair of oxen. And he observes, that they would have a greater velocity than the swiftest three-decked gallies. *Res Memorabiles*, p. 127. Ambergæ, 1599.

An old English writer on military subjects says: "And furthermore you may make a boate to go without oares or sayle, by the placing of certain wheeles on the outside of the boat, in that sort, that the armes of the wheels may goe into the water, and so turning the wheels by some provision, and so the wheels shall make the boate goe." *Invention, or Devises, by William Bourne*, p. 15. London, 1578.

Edmund Bushnel, a shipwright, describes "a mode of rowing ships by heaving at a capstan, useful in any ships becalmed." He connected the oars on each side of the vessel together, and he gave them the alternate backward and forward movement, by attaching the connecting pieces to ropes which were wound and unwound by the capstan. *Compleat Shipwright*, p. 56, fourth edit. 1678.

This was the mechanism he wanted; but before he could avail himself of so fine a thought, it was necessary that he should contrive to convert the alternate motion of his piston-rod into a continuous rotary one. To one so well acquainted with mechanical contrivances there could be little difficulty in doing this; watchmakers practised various modes of converting the one motion into the other, and the one which occurred to Papin was suggested by clockwork mechanism. A rack, *b*, was placed on the piston-rod, working into a pinion, *a*, fastened on the axle of the revolving paddles. He employed two or three steam cylinders, and when the piston of the one was ascending that of the other was working downwards, and as this would give contrary motions, one was detached while the other was in action, and by this means his motion could be made continuous and tolerably regular.

A horse "tow-vessel" was used at Chatham, in 1682. It was constructed with a wheel on each side of the vessel, connected by an axle going across the boat, and the paddles were made to revolve by horses moving a wheel turning by a trundle fixed on the axle. It drew but four and a half feet of water, and towed the greatest ships by the help of four, six, or eight horses: the wheels were permanently fastened to the side of the boat; the capstan, to which the horses were yoked, was not that of the boat. *Savery's Navigation Improved*, p. 18. London, 1698. This, probably, is the identical vessel mentioned in the text.



CHAPTER FOURTH.

"BUT AFTER ALL, COURTEOUS READER, I SHALL COURT YOU TO NO PARTIALITY ON MY SIDE, BUT LEAVE YOU AT YOUR LIBERTY TO JUDGE OF MY PERFORMANCE AS YOU WOULD HAVE ANOTHER JUDGE OF ANY INVENTION OF YOURS. ALL THAT I DESIRE IS, THAT THE WORLD WOULD ACT HONESTLY AND UPON THE SQUARE WITH ME."—*Savery.*

After abstracting those schemes which may be considered as mere suggestions of speculative caprice, or ingenious whim, if the field of improvement appears of narrowed dimension, the soil, at least, is of a valuable and productive character. The elegant toys of Hero, the beautiful experiments of Porta and Decaus, the modifications of the Greek machine by the unknown Italian, the practical merit of the "water-commanding engine," the ingenious ideas of Hautefeuille, and their masterly extension and developement by Papin, contain all the rudiments required for a perfect machine, waiting only to be touched by the wand of some mechanical magician, to form a structure of surpassing ingenuity, and semi-omnipotent power.

The total neglect with which these individual schemes were regarded, is not the least extraordinary circumstance in the history of the steam-engine, and, above all, the oblivion which followed that of Lord Worcester, whose unconquerable persever-

ance, at the lowest ebb of his fortune, found means to carry his splendid ideas into practice. It appears improbable, but that his mechanism, whatever it was, was forced upon the attention of many parties connected with the draining of mines: and from the character of the marquess it is equally remote from belief, that he would fetter the introduction of his invention into general use, by a high price asked for his permission to use it. The utter novelty of the nature and power of the agent, an ignorant and absurd idea of its danger, and the total want, probably, of any mechanical means, except that of mere strength of parts to guard against accidents, may have been the real causes of its neglect, and exclusion from practice.

Thirty years after Lord Worcester's death, a brilliant ray of improvement suddenly bursts into the history of the steam-engine, from the consummation of the labours of a Captain Thomas Savery, who had been silently employed in combining a mechanism, in which elastic vapour was the motive power.

Of the history of this distinguished man little is known. He is to be classed with those whose names alone survive, as connected with discovery or improvement, and to be mentioned with honour, only to heighten the regret, that of a man of whom we desire to know so much, we should know so little. From his pamphlet, on "rowing ships," it appears that he was a person of substance, known to and patronised by individuals among the higher classes of his countrymen. A contemporary incidentally mentions his being a commissioner of sick and wounded seamen; a station, in his time, as it is now, of responsibility and honour. Other authors, deceived by

the title generally prefixed to his name, profess their surprise at a "seafaring man" being so well informed in mechanics. The inference of his being a nautical man is, however, liable to much doubt. In one of his publications he says, that, at an early period of his life, his attention was early directed to water-works; but he almost expressly says, that he never was a seaman: for speaking of introducing an invention of his into ships, he says, "I believe it may be made useful to ships, but I dare not meddle with that matter, and leave it to the judgment of those who are the best judges of maritime affairs."* He was, probably, the director or proprietor of a mine, and, as such, was known by the title which is even now appropriated to the same officer.

He is first presented to our observation as an author of a scheme for rowing ships in a calm, for which, after obtaining a patent, he in vain endeavoured to procure the patronage of government. "The trial of my scheme was unjustly thwarted by one man's humour," said Savery. "A regard to my duty, as well as place, will not permit me to give a biassed opinion," said the umpire. "But I have tried it," replied the projector, "on a small scale, and it answered completely." "So have we," said the servants of government, "and in our trial it failed completely."†

* Miner's Friend, p. 32.

† "I was necessitated to write my book; for after I had racked my brains to find out that which a great many have spent several years in vain in the pursuit of, when I had brought it to a draught on paper, and found it approved by those commonly reputed ingenious, and receiving applause, with promises of great reward from court, if the thing would answer the end for which I proposed it; after I had, with great charge, and several experiments, brought it to do beyond

In the pamphlet in which Savery appeals from their judgment to that of the public, he pays less

what I ever promised or expected myself, at last one man's humour, and more than a humour, totally obstructed the use of my engine, to my no small loss; but it is the nature of some people to decry all inventions, how serviceable soever to the public, that are not the product of their own brains."

He gave an account of it to secretary Trenchard. "A few days after the secretary told me that the king had seen my proposals, and that I need not fear, for that the king had promised me a very considerable reward, and that I must go to the lords of the admiralty to put it in practice; but that *first* I must make a *model of it in a wherry*, which I *did*, and found it to answer my expectations. Then I showed a draft of it to the lords of the admiralty, who all seemed to like it, and one amongst them was pleased to say, that it was the best proposal of the kind he ever saw: so I was referred from them to the commissioners of the navy, who all seemed to like it, but told me that the model must be surveyed by Mr. D——, the surveyor of the navy, whose opinion I asked; but he was very reserved, and said, 'that a wherry was *too small a thing* to show it in, there being no working at a capstan in a wherry:' but he told me 'it was a thing of moment, and required some time to consider on; for should I,' said he, 'give a rash judgment against it, I should injure you; or for it, the charge of putting it in practice must prove a loss to the king, and endanger my employ.'"

After four months' consideration, Dummer gave his opinion against Savery. It was neither a new nor a practicable invention, being similar to one used at Chatham, in 1682, which was abandoned, and he designated, though rather disingenuously, the capstan, and its trundle, as "*clockwork;*" and although Savery "exhibited his wherry on the Thames, and thousands of people were eye-witnesses, and all people seemed to like it, the public newspapers speaking very largely of it, yet all to no purpose." (p. 18.) The inexorable lords of the admiralty were "so much altered, that, from commending the thing, they would not hear one word in its defence." (p. 15.) Savery, notwithstanding, "being informed, by Sir Martin Beckman, the greatest engineer in the Christian world, that the thing was good, got a noble lord to show a draught of it to the king a second time, who ordered me," says Savery, "again to the admiralty, who never ordered me in before them, but, after waiting two or three days, the doorkeeper told me, that my business lay before the *navy*. Upon which, next day, I desired a friend of mine to go with me to the navy-office, that

attention to the reasons urged against its novelty as well as practicability, than they were fairly

he, being a man of extraordinary judgment, and no less reputation, might be an evidence to what discourse might happen; but coming to the navy-office we found the board was rose. However, in the hall I found Mr. D——; I asked him whether any thing was come before the board concerning my business. 'No,' said he, 'not since the objections sent to the lords of the admiralty;' on which he could not but fall into an argument. I asked him some questions in relation to his objections, and, in a very little time, we had a great puther about superambient air and water. I found that my sailor ran himself fast aground, as men commonly do when out of their knowledge; this, indeed, made me pity him again, although I was willing to come at the plain truth of the matter, and asked him whether or no he could not bring one hundred and fifty men to work at this engine, he answered yes; then, said I, will they not have as much power to give a ship motion, as one hundred and fifty men would have on shore, at a hawser fastened to the ship; this he likewise answered in the affirmative. Then, said I, it will do more than oars, or any thing but a gale of wind, and fully answer my proposals. Well, said he, with a smile, and putting off his hat as taking leave, 'WE are all submission to the lords of the admiralty.'

"Not long after, a friend of mine met a commissioner of the navy, and my friend, being perfectly acquainted with my contrivance, asked the commissioner why it was not put in use by them? The gentleman offered several objections, which were, by sound reason, fully answered by my friend, that he had only this hole to creep out at. 'Sir,' said he, 'have we not a parcel of ingenious gentlemen at the board?' 'Yes,' said my friend, 'I hope so, or five hundred pounds per annum is paid them to a fine purpose.' 'Is not Mr. D——,' says the commissioner, 'one of them, and an ingenious man?' 'I hope so,' continued my friend. 'Then,' said he, 'what have interloping people, that have no concern with us, to pretend to contrive or invent any thing for us?'"

Savery, whose bluntness, probably, was no recommendation to his application, has several flings at the "boards," and his statement is wound up by a dexterous one at the contents of courtly Dummer's wig. "Whoever is angry with truth for appearing in mean language, may as well be angry with a wise and honest man for his plain habit; for, indeed, it is as common for lies and nonsense to be disguised by a jingle of words, as a blockhead to be hid by abundance of peruke." *Navigation Improved*, p. 33.

entitled to receive.* In his resentment he says, that "not a tittle will he disclose of two other inventions of his until he has justice done him on account of his rowing engine." The first of these was "a gin of fourteen inches square, portable by one man, and by which one man may lift the largest cannon into her carriage." The second contrivance was a method whereby he could fight any ship, " using charge and discharge as often as six do now, and to as much purpose, without any manner of incommodation, more than by the common way, so that one half of the men need not be exposed that now are, and the rest may be kept as a reserve for boarding; the benefit of this I leave to the ingenious sailor."†

* *Navigation Improved*, or the art of rowing ships, of all rates, in calms, with a more easy, swift, and steady motion than oars can, by *Tho. Savery*, gent. London, 1698. In 1693, a M. Duquet made several experiments at Marseilles, at the expense of the King of France, to navigate a vessel by revolving paddles, or wheels, instead of oars. The results of these trials were very satisfactory, and strongly directed the attention of philosophers, as well as mechanics, to the practicability of this application of water-wheels. *Machines approuvées*, tome i. p. 173.

† Sir Isaac Newton, in a report (dated Leicesterfield, January 27, 1718) which he made to the government, on the practicability of an invention for measuring a ship's way at sea, mentions Savery as the *inventor* of this machine, and notices another of his contrivances. "Mr. Savery, who *invented* the raising of water by fire, told me, about six years ago, that he had invented an instrument to measure the distance sailed, and, by his description, that instrument was much like this, (the one submitted for his opinion,) the sea-water driving round the lowest and swiftest wheel thereof, and that wheel driving round other wheels, the highest and lowest of which turned about an index to show the length of the way sailed."

Savery complained of one of his inventions being neglected, from its resembling a mechanism with which he was unacquainted; but Savery's one, which is now mentioned, was itself only a copy from another described by Bourne, in his

The enthusiasm of the projector was softened in Captain Savery by the experience of a practical mechanic; and he early appears to have acquired that personal consideration, which usually follows a man of genius and enterprise, when his habits are those of a man of business.

At the first announcement of his machine for raising water, he had so matured his ideas, and was so well versed in the nature and power of the motive agent, that his masterly combination has left but minor objects for improvement to succeeding engineers. His mode also of introducing his invention to the notice of the public was totally different from that which had been followed by former projectors. They enveloped every thing in mystery, and endeavoured to attract attention by exaggerated statements of power or economy. His first step was to explain to every one the principles, as well as construction, of his apparatus: he showed why it was a cheaper power than that of horses or men; and

inventions, as produced by a Humphrey Cole. De Saumarez complains, in his turn, of Savery's scheme being remembered by Sir Isaac only to get rid of his claim. The picture he draws of his pursuits and projects is an excellent likeness of a large, but harmless class—can it be named?—of *simple schemers*.

"He was the son of De Saumarez, chaplain to Charles II.; although he was bred in Holland to learn commerce, he never applied himself to any trade or profession, but in *an easy and quiet enjoyment* of his small estate, in the island of Guernsey, he took his diversion in the experimental part of mathematics, his genius or inclination being that way for machines and inventions, wherein he spent about twenty-two years last past, confining himself to a retired sort of life, within his little elaboratory; and of late he fixed his projects upon a particular invention, towards the improvement of navigation, which he could not bring forth to effect in the island for want of able workmen; but he came to London on purpose, and he hath actually begun, and hopes, with the blessing of God, to bring it to some perfection." *Memorial*, p. 4.

he invited practical men to judge for themselves of the value of his assertions and statements, by an inspection of the machine itself in operation.

The influence of the court was, at this period, considered to be essential to the success of any speculation which required the aid of a monopoly. The profits might be diminished or overthrown by the obstacles which avarice and intrigue could then interpose in that quarter to its further progress; and, from this circumstance, considerable importance was attached to having the countenance of those in power to any project in which the pecuniary risk required to be extensive; and Captain Savery might be said to be conforming to an almost common practice, when he exhibited a working model of his fire-engine before King William, at Hampton-court. That monarch, who himself had a mechanical turn, was so pleased with its ingenious construction and effective action, that he took a warm interest in its success, and permitted its author to inscribe to him the account which he published of his contrivance, under the title of "The Miner's Friend."

The great fame of the Royal Society, then adorned by the presidency of Sir Isaac Newton, made its opinion to be listened to with profound respect in matters of science and mechanics. To that body also Captain Savery carried his invention; and in their transactions for that year, is a record of his successful experiment, made in their apartment, and a view and description of the machine forms the subject of an engraving in their anuual volume.

As every form in which it appeared during the lifetime of its inventor is interesting, as showing the steps of its improvement, the model Savery

exhibited before the Royal Society, in 1699,* will require a brief description.

In the engraving marked *Savery*, the pipe, *k*, conducts steam from the boiler (but which, not to crowd the figure, is omitted) into two receivers; a pipe, *i*, branching to each of these vessels, is inserted into their bottom, having valves at *e*, *e*, *d*, *f*, opening upwards, and preventing, by their action, the return of any water which may have been forced through them. A pipe, *h*, proceeding from the cistern, also branches to both receivers, and is inserted into the top of each. Valves are placed at *c*, *c*, by which a communication may be opened, or shut off with the boiler, and each receiver, alternately, accordingly as they may be adjusted; one being open when the other is closed.

Steam from the boiler being permitted to flow into either of the receivers, the water which that receiver contains is forced by the steam from the boiler, pressing upon its surface, up one of the branches of the pipe, *i*, and when the vessel is, by this means, emptied of the water which it contained, and filled with steam, by turning the cock, or valve, *c*, the communication with the boiler is shut off; *cold water* is then poured over its surface; this, cooling the apparatus, condenses the steam which it encloses, and, by this means, a vacuum is formed *within* the receiver, and the pressure of the atmosphere forces the water of the cistern up the pipe, *h*, into the empty vessel. At the instant in which the steam was shut out from the one receiver, by turning the other valve it was permitted to flow into the opposite one, and it forces the water which it contains up the pipe, *i*, during the time that the condensation is

* Phil. Transactions, vol. xxi. p. 228.

being produced in the other vessel. When the steam has expelled all the water, and completely fills this receiver, cold water is thrown on the outside of the vessel; the steam within it is condensed also, and the pressure of the atmosphere acts again to raise the water of the cistern up the pipe, *h*, into the second receiver, in which a vacuum has thus been produced. The cock, *c*, by which the communication was interrupted, when the first receiver was filled with steam, is now turned the contrary way; the steam again flows into that vessel, which has been in the interval filled with water, and begins to force the fluid upwards, as before; and this alternate emptying and refilling of the cylinders may be prolonged at pleasure.

Such was the first form of Savery's celebrated engine for raising water by fire: before, however, he offered it as a machine admirably adapted for the purpose of raising water from mines, many essential parts were to be added, and all were to be constructed to offer a precise and determinate action.

These appear to have been supplied before 1702;* at that time he dates his address to the "Gentlemen Adventurers in the Mines in England," and gives a detailed account of the construction and action of his machine, a concise view of some of its advantages, and enumerates the purposes to which it

* *The Miner's Friend;* or a description of an engine for raising water by fire, with an answer to the objections against it. By Thomas Savery, Gent. London, 1702. Reprinted, soon after its publication, in a quarto form, along with Decaus's book. "A new and rare invention of water-works, teaching how to raise water higher than the spring, as also a description of Captain Savery's engine for raising vast quantities of water by fire." London, 1704. The experiments on steam are omitted in this reprint also of Decaus. The engraving prefixed to the *Miner's Friend* is given in this volume.

could be applied with greater economy than the labour of animals.

Surprising as it seems, yet, with all this publicity and honourable candour, the admirable Savery, was nearly, in his career, experiencing the neglect and failure which had attended Lord Worcester's similar one, thirty-five years before. The general incredulity attached to schemes of projectors, not only excused the opposition and ignorance of those whose interest (in their own view) was opposed to its introduction, but deterred others from giving it a trial, whose property was rapidly deteriorating from the want of that assistance which Savery's engine was so well fitted to *bestow*. To the latter he said, "I leave it to your consideration, whether it be worth your while to make use of it or no. But let not the failures of others prejudice me, for I have spared neither time, nor pains, nor money, till I had absolutely conquered every difficulty. Its power is in a manner infinite and unlimited, and will draw you water five hundred or one thousand feet high, were any pit so deep, and that you could find us a way to procure strength enough to support such an immense weight as a pillar of water one thousand feet high would produce. I dare undertake, that this engine shall raise you as much water for eightpence, as will cost you a shilling to raise the like with your old engines, which is thirty-three pounds six shillings and eightpence saved out of every hundred pound; a brave estate gained in one year out of such great works, where three, six, or it may be eight thousand pounds per annum is expended for clearing their mines of water only, besides the repair of gins, engines, horses, &c." *

* Miner's Friend, p. 77.

To the artisans engaged in the construction of the common machinery, and who dreaded, in the introduction of a new machine, the loss of that employment which, from time immemorial, had been derived from the erection and repair of the old, he urged, that still they would be more than amply employed by the opening of other channels for labour. "The cheaper," he says to them, "that water is drawn, the more is the miner encouraged to adventure; the more the miner adventures, the more pits or shafts must be sunk; the more pits and shafts must be sunk, the more wood-work will be necessarily employed in timbering them. The windlasses, and other utensils used of wood, must be more, which, by increasing the carpenter's trade in general, will make them sufficient amends for the loss of a small branch of their business in gin making."*

Lest their fears should not be allayed by this mode of stating the matter; lest they might blindly shut their eyes to the fact, that the extension of machinery to purposes hitherto performed by human power, could only (after a season) have the tendency of raising the value of labour, in general, he soothed them by promises. "I shall never employ any other person, in making pipes, or any other carpenter's work that I shall have to do, but the person who was before employed in the work; for it is not my design, in the least, to prejudice the artificers, or, indeed, any other sort of people, by this invention; but, on the contrary, is intended for the benefit of mankind in general."†

The labour, expense, and fatigue of invention had been surmounted; but still the task of introducing his machine, and of getting a fair trial for

* P. 6, *ibid.* † P. 7, *ibid.*

its merits, was now found to demand an almost Herculean exertion and perseverance. The sins of former projectors were remembered to the disadvantage of Savery. Again he says, "Time out of mind there have been mountebanks and impostors in all faculties, who pretend to great things but do perform nothing effectually, and it would be hard if that should be drawn into consequence, that because some are knaves therefore none are honest." And Savery assured the "gentlemen adventurers in the mines of England," that his machine was not like many that had preceded him. "I am not fond of lying under the scandal of a bare projector: I can easily give grains of allowance for your suspicions, because I know very well what miscarriages there have been by people ignorant of what they pretend to. These, I know, have been so frequent, so fair and so promising at first, but so short of performing what they pretended to, that your prudence and discretion will not now suffer you to believe any thing without a demonstration, your appetites to new inventions of this nature having been balked too often; yet, after all, I must beg you not to condemn me, before you have read what I have to say for myself, and let not the failure of others prejudice me, or be placed to my account. I have often lamented the want of understanding the true powers of nature, which misfortune hath, of late, put some on making such vast engines and machines, both troublesome and expensive, yet of no manner of use; inasmuch as the old engines used many ages past far exceeded them: and, I fear, whoever, by the old causes of motion, pretends to improvements within this last century does betray his knowledge and judgment; for more than one hundred years since men and

horses would raise, by engines then made, as much water as they have ever since done, or, I believe, ever will, or, according to the law of nature, ever can do; and though my thoughts have been long employed about water-works, I should never have pretended to any invention of that kind, had I not happily found out this new, yet a much stronger and cheaper force, or cause of motion than any before made use of. But finding this, of rarefaction by fire, the consideration of the difficulties the miners and colliers labour under by frequent disorders, cumbersomeness, and, in general, of water-engines, encouraged me to invent engines to work by this new force; that though I was obliged to encounter the oddest, and almost insuperable difficulties, I spared neither time, nor pains, nor money, till I had absolutely conquered them."*

One of his greatest difficulties arose from the want of skill in his workmen; but this he, in the end, succeeded in surmounting; and, in 1702, he writes, that "he had met with great difficulties and expense to instruct handicraft artificers to form my engine according to my design; but my workmen, after so much experience, are become such masters of the thing, that they oblige themselves to deliver what engines they make me exactly tight and fit for service, and, as such, I dare warrant them to any body. So I hope I may assure myself of due encouragement from the ingenious, who are ever studious to promote all inventions useful and beneficial to the public; for they must conclude, that an engine, which for some time has daily employed the best artificers to work on it, was not to be brought forth in one day; and to bring it to that perfection you now

* P. 2, *ibid.*

find it, must have cost me and my friends not a little money to make workmen capable of their work, with that certainty and exactness they now do."*

The first use to which this admirable mechanic suggested the employment of his machine, was to raise water into a reservoir to produce a rotary motion by its fall on a water-wheel; and he then gives some directions for a mode of estimating its power. "I have only to urge," says he, "that water in its fall from any determinate height has simply a force answerable, and equal to the force that raises it; so that an engine which will raise as much water as two horses working together at one time in such a work can do, and for which there must be constantly kept ten or twelve horses for doing the same; then, I say, such an engine will do the work of ten or twelve horses." He further proposes to raise water by it for the use of "palaces and gentlemen's houses;" "for serving cities and towns with water;" for "draining fens and marshes;" and remarks, that it is much cheaper here than horse engines, "especially where the coals are water-borne." He believes it may be useful to ships, probably for pumping; and, lastly, for the draining "of mines and coal-pits;" and for "the cure of damps by the air perpetually crowding into the ash-hole and fire-place, as it is natural for it to do, and with a most impetuous force discharged with the smoke at the top of the chimney, the contiguous air is successively following it, so that not only all steams or vapours whatsoever that may or can arise, must naturally force its way through the fire, and so be discharged at the top with the smoke, and the motion of the fire will occasion the fresh air to

* P. viii. *ibid.*

descend from above, and here will be a perpetual circulation of the air, and with that swiftness as is hardly to be believed." He also describes an arrangement by which it could be applied to the extinction of fires, "without the hand labour of pumping or bailing with buckets."

The directions he gives for the erection of his engine, and also the description of its parts, are minute and circumstantial; but of the dimensions he says but little. The furnace was so contrived, that the flame took a turn or two round each of the boilers, "which," he says, "any bricklayer used to furnaces could manage, it being performed by running a row of bricks round them both like a screw or worm, which being contiguous to the wall of the furnaces and the boilers, makes it, as it were, a worm-funnel round them both." The greatest boiler belonging to his engine was between twenty-four and thirty inches diameter, and was, when occasion required, made much narrower and deeper. An engine having a pipe of delivery of three-inch bore, working the water sixty feet high, had a fire-place of not above twenty inches deep, and fourteen or fifteen inches wide: but he said, that "the quantity of coals used for one engine in a year could not easily be ascertained, because of the different nature of the several sorts of coals."

The valves of his engines were constructed of brass, as were also the screws. The boilers, receivers, and the pipes, communicating from the pit to the receivers, were made of copper; the discharge pipes, in his engravings, are shown as made of wood.

The five engravings marked *Savery*, which are given, it is hoped, will fully explain the construction of his machine; and, with a brief enume-

ration of the various parts of which it is composed, will be sufficient, to explain the principle as well as the mode of its action. The inventor's own account, given in his treatise, which he entitled the "MINER'S FRIEND," will be found as amusing, lively, and original in the manner, as it is candid, ingenuous, and circumstantial in the points connected with the principle and operation of his exquisite mechanism. To understand fully the great merit of Savery as an inventor, it is necessary to peruse his celebrated treatise; and as the original edition has now become of exceeding rarity, and great price, it has been reprinted in the same size with these *Anecdotes*, and is sold at a price which makes it accessible to all: we gladly, therefore, refer to this interesting record of his genius for the most ample details. Here our space limits us to a brief abstract only of part of his description.

The engraving numbered II. is an *elevation* of this apparatus; IV. a section of the same; III. contains some of the parts more in detail; and the engraving having the title *Savery*, without any distinguishing number, is a *side view* of the same apparatus. With one exception, which we have noticed in its place, the same letter, in all the figures of the plates marked *Savery*, refers to the same parts of the mechanism: *a*, the furnaces; *b*, B, the fire-places; *c*, the chimney; *d*, the small boiler; *e*, its pipe and cock, closed by the screw, *f*; the small pipe, *g*, goes within eight inches of the bottom of the boiler; *h*, a pipe of greater diameter, is inserted to the same depth, having a valve or clack, *i*, opening upwards; the pipe, *k*, may be considered a continuation of the box containing this valve, and is inserted about an inch below the roof of the larger boiler, *l*; *m*, screws which adjust the

regulator; *n*, a small cock and pipe going somewhat more than half way into the larger boiler; *o*, O, steam pipes, one end of each being inserted into the roof of the large boiler, and the other end of each being inserted into one of the receivers, *p*, P, forms communications between each of those vessels and the boilers; *q*, *q*, are the screws by which the pipes are fastened together; *r*, *r*, R, R, valves or clacks of brass, constructed so that they may be opened and inspected at pleasure; *s*, the pipe through which the water that is forced from the receiver, is conveyed into the cistern at the required height; *t*, the pipe connecting the cistern from which the water is to be raised with the receivers; *x*, a cistern with a buoy cock proceeding from the forcing-pipe, *s*, having a pipe, *y*, constructed so as to be easily moved round upon each of the receivers, *p*, P; *z*, the handle of the regulator.

The boilers being previously filled to the necessary height with water, all the cocks being shut: the valves in their proper positions: and the receivers empty, a fire being made under the large boiler and the water it contains being made to boil: and steam raised of a temperature, as much higher than 112° as may be necessary, (to balance a column of water, equal to the height between the bottom of the receivers and the upper surface of the water in the cistern into which it is to be elevated,) then turning the handle, *z*, of the regulator, will open a communication between one of the cylinders and the boiler. Suppose a passage for the steam opened through the pipe, *o*, into the receiver, *p*, the orifice of the other pipe, O, in the roof of the boiler, will be closed by the sliding valve; by the influx of the steam all the air which was contained in the receiver, *p*, will be expelled through the valve, *r*,

into the empty pipe, *s*. If the handle of the regulator be now turned, the further flow of steam from the boiler is prevented; the pipe, *y*, is then to be moved so as to allow a quantity of cold water to fall upon the vessel, *p*; this almost instantaneously cools that vessel, and thus condenses the vapour which it contained into a very small portion of water, about the eighteen hundredth part of the quantity of steam which formed it: *a vacuum* is thus produced nearly perfect within the receiver. The pressure of the atmosphere upon the water in the cistern now forces it up the pipe into the receiver, and fills it; the same operation takes place with the steam and water in the other receiver, and both vessels are thus filled with water.

The handle of the regulator is again turned into its first position, by which the steam is shut off from the pipe, O, and allowed to flow through *o* into the receiver, *p*; the elastic vapour pressing upon the surface of the water in the receiver, forces it (as it did the air) through the valve, or clack, *r*, up the pipe, *s*, into the cistern or reservoir at the required height. When all the water has been expelled from this receiver, by turning the handle, *x*, the further supply of steam is cut off, and it now flows into the other receiver, and impels the water it contains also up the pipe, *s*; but while this operation is going on, the water pipe, *y*, is again brought over the receiver, *p*, which is filled with steam, and a jet of cold water falling upon it, the vapour it contains is a second time condensed, and the pressure of the atmosphere, as before, forces the water from the cistern to replenish the vacuum in the receiver. When the steam has forced all the water from the other receiver, P, the fall of cold water from the movable pipe, *y*, also condenses the vapour with which it is filled, a

vacuum is formed, and this vessel is also replenished by the pressure of the atmosphere: the same process is alternately repeated, and may obviously be continued as long as there is any steam generated in the boiler, and water in the cistern to be forced up the pipe, *s*, to replenish the vacuum produced in the receiver by the condensation of the vapour.

The action of this apparatus would cease after all the water had been evaporated from the large boiler, and during the time it was replenishing, and until the fresh supply had received the necessary temperature; this, in practice, would have been a serious obstacle to its use in a great many situations. The mode by which Savery replenished his large boiler, without lowering its temperature, and thus ensuring a perfect continuity in its action, almost exceeded in ingenuity the invention of the engine for raising water by fire itself. In the figures, the two boilers are shown as connected by a pipe, (marked *n*, in fig. 12, and *k*, in fig. 5, Plate III.) When the water has evaporated to a certain quantity in the large boiler, a fire is made under the smaller one; and as no part of the steam is permitted to escape from this vessel, its elasticity or temperature quickly exceeds that in the larger boiler, which is constantly flowing into one or other of the receivers. The vapour, therefore, in the boiler, *d*, will force the water up the pipe, *h*, and raising the valve, *i*, and flowing along the pipe, *k*, into the large boiler, will replenish the waste which has arisen from evaporation. When the water has been expelled from the small boiler to the level of the pipe, *h*, cold water is introduced through the cock, *e*, which communicates by a pipe, *e*, with the rising pipe, *s*, to be again introduced at a high temperature into the larger vessel; the valve, *i*, by

opening upwards, prevents the steam in the larger boiler from flowing into the smaller during this operation. The small pipes, *g* and *n*, go to within eight inches of the bottom of each boiler; by opening their cocks on the outside of the boilers, they serve as indexes for ascertaining when the water in each has nearly evaporated. When steam only comes through either on opening their cocks, the water has sunk beneath their lower orifices; and as these are adjusted to the lowest level at which it ought to stand, it gives notice that a fresh supply is necessary; but if water comes through on opening the cock, the quantity contained in the boiler is sufficient to prevent accidents from its being burnt by the fire beneath it.

The mechanism by which the steam is directed into either of the receivers, is very simple, and will be easily understood by an inspection of figs. 3 and 4, the part marked *m*, in fig. 1, and a bird's-eye view of the same part in fig. 2. A slider is attached to an axis or spindle, *m*, going through the lid of the boiler; when the handle, *z*, fixed on this, is moved backwards or forwards, it causes the slider (shown in its two different positions in figs. 3 and 4) to shut the mouth of one of the pipes, *o*, O, and thus interrupts the flow of the steam into that receiver, with which it is connected. The operation of the buoy cock, and the jet cock and its pipe, will be easily understood from an inspection of the figure forming the subject of Plate IV. All the valves or clacks in the pipes being constructed to open upwards, the return of the water, which has been raised to its former place, is effectually prevented.

Such is the arrangement of the parts and action of the celebrated fire-engine of Captain Savery; and various as the opinions are regarding his claim

to the merit of being its original discoverer, or first contriver, there is but one with regard to the usefulness, power, and beauty of his invention; and even if it be considered as but a combination of existing ideas, their masterly adaptation marks a mind of the highest order.*

* "Captain Savery," according to the doctor, "having read the Marquess of Worcester's book, was the first who put in practice the raising of water by fire, which he proposed for the draining of mines. His engine is described in Harris's Lexicon, which, being compared with the Marquess of Worcester's description, will easily appear to have been taken from him, though Captain Savery denied it; and the better to conceal the matter, bought up all the marquess's books that he could purchase in Paternoster-row, and elsewhere, and burned them in the presence of a gentleman who told me this. He said, that he found out the power of steam by chance, and had invented the following story to induce people to believe it, viz.: that having drunk a flask of Florence wine at a tavern, and thrown the empty flask upon the fire, he called for a basin to wash his hands, and *perceiving* that the little wine left in the flask had filled up the flask with steam, he took the flask by the neck, and plunged the mouth of it under the surface of the water in the basin, and the water of the basin was immediately driven up into the flask by the pressure of the air: now he never made such an experiment then, nor designedly afterwards, which I thus prove. I made the experiment purposely with about half a glass of wine left in a flask, which I laid upon the fire until it boiled into steam, then putting on a thick glove to prevent the neck of the flask from burning me, I plunged the mouth of it under the water that filled the basin, but the pressure of the atmosphere was so strong, that it beat the flask out of my hand with violence, and threw it up to the ceiling. All this must have happened to Captain Savery; if ever he had made the experiment, he would not have failed to have told such a remarkable incident, which would have embellished his story," *Experimental Philosophy*, vol. ii. p. 314.

"This grievous charge," says professor Robison, "ought to be substantiated by very distinct evidence; yet Desaguliers produces none such, and he was too late to know what happened at the time. His argument is a very *foolish* one, and gives him no title to consider Savery's experiment as a falsehood; for it might have happened precisely as Savery relates, and not as it happened to Desaguliers. The fact is, Savery

We may pass over with brief notice the charge made by Desaguliers, and by him alone, of Savery

obtained his patent in 1698, after a hearing of objections, in which the discovery of the Marquess of Worcester was not mentioned; but, besides this, he had erected several of his engines before he obtained his patent." *Mechanical Philosophy*, vol. iii. p. 148. 1824.

"Every possible publicity was given, not only to the principle of his machine, but also to its construction; and yet, during Savery's lifetime, the Marquess of Worcester's description had never been mentioned. Neither is this tale of destroying the books found in any other author. Nor is it stated by Desaguliers before 1746, nearly thirty years after Savery's death, and almost fifty years after the grant of the patent. Desaguliers alludes to the Marquess of Worcester's *book*: Was the doctor ignorant of the noble inventor having printed *two* (four) books containing the description? Did the other three become scarce? Copies of these might have been in existence to have produced against Savery's claim, and destroyed his patent. It is certain that, during his lifetime, Savery is not known to have had any competitor in England to dispute with him the honour of inventing the machine which now bears his name; but a pamphlet being rare at a bookseller's thirty-five years after its publication is not at all an extraordinary circumstance; and it would, indeed, have been almost a miracle had a copy of the book been found at such a distance of time in that unenviable situation." Stuart, *Des. Hist. of Steam Engine*, p. 35.

"No contrivance," says Switzer, (*Introduction to a general System of Hydrostatics*, 1729,) "is more justly surprising than the fire-engine, the particular contrivance and sole invention of a gentleman with whom I had the honour, long since, to be well acquainted. I mean the ingenious Captain Savery, sometime since deceased, but then a most noted engineer, and one of the commissioners of sick and wounded. This gentleman's thoughts were always employed in hydrostatics, or hydraulics, or in the improvement of water-works; and the first hint from which it is said he took this engine was from a tobacco-pipe, which he immersed to wash or cool it, as is sometimes done. He discovered, by the rarefaction of the air in the tube by the heat or steam of the water, and the gravitation or impulse of the exterior air, that the water was made to spring through the tube of the pipe in a wonderful, surprising manner; though others say, that the learned Marquess of Worcester, in his "Century of Inventions," (which book I have not seen,) gave the first hint for thus raising water

having copied his machine from the descriptions left by Lord Worcester; and taking advantage of the death of the original inventor, to produce his machine a second time, and claim for it, as for his own idea, that protection which was only to be granted to an original discovery.

Savery, it is admitted, may have read the description in the "Century of Inventions," and he may even have been acquainted with the details of

by fire. It was a considerable time before this ingenious person, who has been so great an honour to his country, could, as he himself tells us, bring this, his design, to perfection, on account of the awkwardness of the workmen, who were necessarily to be employed about the affair; and I have heard him say myself, that the first time he played it was in a potter's house at Lambeth, where, though it was but a small engine, yet it forced its way through the roof, and struck up the tiles in a manner that surprised all the spectators." p. 324.

In 1730, Dr. Allen says: "It is now more than thirty years since the engine for raising water by fire was first *invented* by the *famous Captain Savery*, and upwards of twenty years that it received its great improvement by my good friend, the ever-memorable Mr. Newcomen, whose death I very much regret." *Specimina Ichnographica*, p. 17.

Another of his inventions is described by M. de Saumarez, who had invented something similar, and whose scheme was recognised to be the same as Savery's. "It was towed sometime by the side of the ship and sometime by the stern. The sea-water driving round the lowest and swiftest wheel thereof, and that wheel driving round other wheels, the highest and lowest of which turned round an index covered with glass to show length of way sailed. When it was fair weather and bore before the wind, it showed in a manner the distance sailed, which was performed by hauling on board to view the index, and reputting it off again from the side of the ship into the sea with great care and precaution lest it should be bruised, which proved cumbersome and troublesome to the seamen, and of no dependence to be made upon, much less when the ship did veer and tack about or kept to the windward; and that it was useless in a rough sea, and on the whole found less exact than the log-line, and at Captain Bennet's coming home he delivered the instrument to Savery." Saumarez's *Memorial*, p. 10. 1717.

Lord Worcester's machine at Vauxhall, and yet be neither an imitator nor a plagiary. Many of Lord Worcester's contemporaries were alive at the period when Savery got his patent; some of them were members of the Royal Society at the time he exhibited his model, and described its construction and action in their apartment, among others, the celebrated Dr. Hooke. It is improbable, therefore, that Lord Worcester's machine, whatever was its construction, could have been unknown or forgotten by many of the eminent persons then composing that body; and particularly by Dr. Hooke. The doctor's memory was not one of the least retentive, and his habits of mind, certainly, were not those which, at any period of his long life, would have permitted him to see the merit of a machine of this importance arrogated by a person who had no claim to it; and the more so, as the doctor *himself* is said to have hinted at the construction of a steam-engine so early as 1678: * and finally, it is equally improbable, that others were not to be found, whose testimony would have been brought against Savery at the legal hearing of

* "After the death of Dr. Robison, says the author of a memoir of Dr. Hooke in the Edinburgh Encyclopædia, 'there was a list of Dr. Hooke's inventions found among the professor's papers, which contained the following memorandum:'—'1678, proposed a 'steam-engine on Newcomen's principle.' It would have been interesting to have ascertained whether this memorandum was made by Dr. Robison before or after his having written the excellent account of the steam-engine in his supplementary articles to the third edition of the Encyclopædia Britannica. The project was either unknown to the professor, at the period of writing the article alluded to, or it was rejected on account of its questionable accuracy. In the edition of that account lately published, (in his "Mechanical Philosophy," 1823,) no notice whatever is taken of Hooke's idea." Stuart, *Des. Hist. of Steam-engine*, p. 21. 2d edit. 1825.

objections which were made against his invention, before he got a grant of a monopoly of the profit which might arise from his permission to construct and use this novel apparatus.

The line between the engines of Worcester and Savery might, conjecturally, be easily drawn, so as to define, with the greatest probability, the merits and claims of both. Lord Worcester expressly says, his machine did not draw or suck upwards; that is, it did not produce any part of its effect by the aid of atmospheric pressure. This is a material point; for this agency was one of the most distinguishing features in Savery's machine. He combined the elastic force of steam with that which was derived by condensing the vapour to form a vacuum; and thus availed himself of the pressure of the atmosphere not only to increase the power, but even to form the sole means by which he produced the effect in his engine. In all his descriptions, it is remarkable that he never once produces the entire effect by the elasticity *alone* of the vapour; but in describing an arrangement for draining fens, he says, this could be done solely by *condensation*. The opinion, therefore, that Lord Worcester's apparatus was similar to a high-pressure engine, receives a strong corroboration from the circumstance of its not having been an effective bar to Savery's privilege of monopoly; and on the other hand, the total difference in the construction of each, places Savery's merit in a new and more interesting view, and on a broader basis.

Even, therefore, admitting, in the fullest and most unequivocal terms, that Savery was intimately acquainted with his predecessors' labours in this particular species of mechanism, his merit in the formation of his apparatus was as great as that of

any of his rivals'. Lord Worcester could not be ignorant of Porta's, Decaus's, and Kircher's schemes. Savery, probably, did not throw away the advantage he had of adding the marquess's, and Hautefeuille's, and Papin's experience to these; for his machine certainly embodies nearly all their ideas. Hero, Porta, and Decaus mention the condensation of steam by the *cold from the air,* and the means of replenishing the vacuum by the pressure of the atmosphere; Porta and Decaus raised water through a pipe by the elasticity of steam pressing upon its surface. Hautefeuille and Papin describe similar contrivances, and the latter, particularly, made wonderful strides in improvement on his predecessors. Yet, how prodigious the difference between the most refined of these and the celebrated machine of Savery! How many essential parts were to be supplied from the stores of his own comprehensive and fertile imagination! How many difficulties were to be overcome! And how many original and masterly connecting ideas may not be traced in the imperishable monument of his genius, his "engine for raising water by fire." Among these may be named, raising the steam in a boiler, conducting it into a *separate vessel; condensing* it there by *artificial means,* and with *instantaneous rapidity;* making the production of the vacuum from an auxiliary become a principal cause of its wonderful effects; producing a *continuity in its action* by the *arrangement* of the parts of his machine; in aid of this latter purpose, *replenishing his larger boiler with water,* without *lowering* the temperature of that which it already contained; the use of *small pipes* to know when it was necessary to introduce the supply of water; the fine mechanism of the *sliding*

valves; the ingenious construction of the cold-water pipe; the precision with which all the parts were adjusted to aid in the action of each other; and though last in the enumeration, not least in merit, his admirable arrangement of the *parts*, and sagacious selection of *forms*, and their *effective* connection;—all these, which were the achievements of his own genius, have left to succeeding mechanics but few opportunities of supplying omissions, or remedying defects; and this admirable machine, in form and construction, is now nearly the same as when it first proceeded from the masterly hand of its excellent inventor.

At this period the exertions of mechanics in France to derive a power from the action of heat, discovered the usual refined ingenuity of that accomplished people; but the results of their labours are considered to have been, on the whole, unsuccessful, inasmuch as they wanted the merit of fitness for practice, which was possessed in so eminent a degree by the machine produced among their insular rivals. The inventor of a steam-wheel is found in the ranks of its most distinguished and industrious philosophers.

Guillaume Amontons, the son of a Norman advocate, who settled at Paris, was afflicted, from childhood, with so great a deafness as nearly to deprive him of the society and conversation of mankind. He began the study of machines for his amusement, and his first essay was an attempt to construct an apparatus to produce a perpetual motion; a perseverance in this research taught him, that he had lost the time he had expended on it, and thrown away his care. The family of Amontons was opposed to these studies from their beginning, as leading neither to distinction nor to fortune; but the student despairing, after the

failure of a course of medical and surgical experiments, of ever obtaining his hearing, redoubled his attention to mathematical and mechanical pursuits. He designed buildings with taste, and in works of carpentry introduced some theoretical refinements to improve its practice; he invented an ingenious telegraph for conveying a message from Rome to Paris in three or four hours, and the experiment was tried with success in the suburbs of Paris. His works on hygrometers and barometers are of great merit; and his theory and experiments on friction are still appealed to for their ingenuity as well as accuracy: for his invention of the "moulin à feu," he ranks as an early improver of the steam-engine. But the amiable qualities of his mind exceeded even the ingenuity of his spirit. Amontons was proverbial for the frankness, and simplicity, and polish of his manners, and for the almost infantine benevolence of his disposition.

The scheme of Amontons, totally different from the idea of Savery, and unique of its kind, thus early attracted the attention of mechanics to supply a desideratum of a continuous rotary motion from the elasticity of steam. The machine was called, by its inventor, a fire-wheel, and described as operating by the action of *heated air*, forcing a quantity of water up one side of a wheel and producing a rotary motion by its differing weight from the other side.

Like some of his contemporaries, Amontons appears partial to the expansion of air,* and to have *forced* it into his service in the construction of his engine. Upon the authority of his own drawing it would appear, that the presence of air in his

* Memoires de l'Académie des Sciences, p. 208. 1699. Bossut, Hydrodynamique, tome ii, p. 307.

apparatus was more to be avoided than introduced, and that, in fact, all its effective power would be derived from steam. A cursory inspection of his "moulin à feu" will show us, that the water in the inner range of chambers would soon become intensely heated and form vapour, which could not, by any mechanism he has shown, be prevented from filling what may be designated the air-chambers.

The fire-wheel, as described by its author, consists of two concentric ungulas or rings, connected and communicating by means of small pipes, 1, 2, 3, 4, &c. The outer ring of the wheel is divided into a certain number of compartments, a, b, c, d, e, f, &c. Amontons describes his as having twelve, and perfectly closed, so as to have no connection with each other. The inner ring is divided into the same number of compartments, marked *a*, *b*, *c*, *d*, *e*, *f*, &c.; each of these communicates with the adjoining chamber by a valve made in each compartment moving on a hinge, and only opening in one direction, and that upwards. Although the two rings and their series of compartments are placed at a distance, each compartment of the one communicates with a corresponding division of the other by small pipes, 1, 2, 3, 4, &c. The wheel is placed so as to have one side of its periphery exposed to the action of a fire, and the other side is immersed in a cistern, *y*, of cold water. Four or five of the lower chambers of the inner series are filled with water.

A fire is then, says Amontons, to be made in the furnace: this will heat the air in the chamber (for example, marked *a*) of the outer series, which is exposed to its influence, and the air which it contains is rarefied, and flowing through the pipe

(numbered 1) into the chamber, *a*, of the inner series, presses upon the water which it contains, and as the construction of the valves allows it to flow only in one direction, it is forced upwards into the divisions on that side of the wheel nearest the furnace; this gives it a preponderance, and it descends. The cell, *a*, is now in the position at first occupied by *b*, and *c* is in that where it begins to enter the cistern; the air which is contained in the divisions which had been heated now being brought into contact with the water, it is condensed, and continues so, until, by the revolution of the wheel, it is again brought, in its turn, into contact with the fire of the furnace.

Nothing can be simpler than the hypothetical action of this mechanism; its effect was, as usual, not underrated. The wheel was twelve feet in diameter, and the cells were calculated to contain 750 cubic feet of water, and an entire revolution to be made in about thirty-five seconds. This great weight, applied tangentially to one side of the wheel, was to give it a continuous preponderance, which was calculated, very minutely, to equal in effect the power of nearly thirty-four horses, or two hundred and thirty-four men.

Throwing the practical merit of this mechanism totally out of the question, the combination is exceedingly meritorious; and considering the time of its invention, and the perfect novelty of the idea, it has many claims to a more favourable consideration as a first thought, than has usually been awarded to it. That it presents glaring defects cannot be denied; but had length of years been allotted by Providence to its amiable projector, the same ingenuity which first traced the outline might have effectively supplied its deficiencies. A negative proof of its merit is, that it has been

the type of several attempts at the construction of steam-wheels among later mechanics. Daslesme, his contemporary, fell prodigiously behind him in his idea for raising water by steam; the model, it is said, acted in a manner similar to Decaus's. A notice of it is here introduced, from a wish not to omit the labours of any who, at a time when the subject was little regarded, thought it worthy of their observation and attention.

While Amontons, in France, was engaged in his steam-wheel, and Savery, in England, had achieved so brilliant a triumph, Papin was again exerting himself at Marpurg, in Germany, to bend the same powerful agent to the use of man; "as if the three nations of Europe, which had made," says Belidor, "the greatest advances in science, were each anxious to furnish a learned man to participate in the glory of so fine a discovery."

In considering the circumstances under which Papin carried on his researches, it is extraordinary that he should have stumbled, as it were, on so admirable a modification as that described by him in 1695, and abandon it almost at the moment when he had in his grasp a brilliant reward for his life of labour. But we learn from the taunts of his rivals, as well as his own confession, that his sanguine hopes and laborious perseverance ended only in pointing out one or two properties of an agent, whose peculiarities foiled all his boasted ingenuity to bend its agency to strictly practical purposes. At the period (1698) of discontinuing his researches he had made considerable progress in an experimental machine; but the frosts of the following November damaging the apparatus, by destroying the valves which were placed in the

river, was an accident which so discouraged Papin, that the further prosecution of this experiment yielded to matters of less importance, and the machine itself was completely forgotten.*

Few philosophers in his time had such rare facilities of performing experiments, or more ample means to carry his ideas into practice, or more gratifying attention to incite him to perseverance. The Elector of Hesse, under whose patronage he resided in Germany, inheriting that love of science, which, for generations, gloriously distinguished his ancestors, not only furnished the means, but condescended to become his associate in the labour of experimenting.

This enviable position had made his operations to be regarded with great interest by a large circle of men of science, with whom he maintained a liberal and friendly intercourse. The celebrated Leibnitz was numbered among the correspondents of the philosopher of Marpurg; and to him, among others, Papin explained his objects, described his experiment, and related his failure. The ingenuity of the mathematician, however, elicited no device by which his friend could be assisted; but his reply informs us, that years before the period at which he was writing, (June, 1698,) the expansion of steam had presented itself to his mind as a source from whence might be derived a cheap mechanic power.

Thirty years of experiment not having conducted to any useful discovery, offered to Papin no inducement longer to tread a path apparently so barren. But the indifference produced by his own want of success was destined to be stimu-

* Nouvelle-manière pour lever l'eau par la force du feu. Mise en lumière par M. D. Papin, Dr. en Méd. Prof. en Mathém. à Marbourg, p. 3. A Cassel, 1707.

lated by the better fortune attending the labours of another. And the great fame which Savery had acquired in England again roused the ambitious industry of Papin to forget former failures in the pursuit of new distinction.

The rival of the illustrious Newton, during one of his visits to England, had seen the *machine for raising water by fire* in action. The experiment of his Marpurg correspondent was then recalled to his recollection; and at his return to Germany, Leibnitz sent a copy of the "Miner's Friend" to Papin, to have his opinion on its merit.

It may be observed, that Savery's engine, which was figured and described in the "Philosophical Transactions for 1698," does not appear to have excited Papin's attention as a project. It presented so many difficulties to be surmounted, that Papin, after his own experiments, might be pardoned forming the opinion that Savery's scheme would prove abortive.

But the testimony of Leibnitz, after an inspection of the apparatus, set conjecture at rest. His letter, and Savery's treatise, being submitted to the elector, the subject of the neglected model was resumed, and the prince again became the colleague of the philosopher in the labour of experimenting. The result was the production of a machine, which Papin ascribes to the ingenuity of his royal patron; in the description of his apparatus he claims no other merit for himself, but that of an experienced assistant and a grateful narrator.

At first view, it bears a strong resemblance to Savery's engine; but on a more careful inspection, it will be found to vary in almost every essential point. It may also be added, it differs prodigiously from the English mechanism in its practical value.

The engraving marked *Hesse* contains a view of the exterior appearance of the elector's engine; and the figure beneath it is a section of the same apparatus; *a* is the boiler, having a pipe, *b*, closed by a lever valve, through which it is supplied with water; the pipe, *d*, connects it with the forcing vessel, *f*; *s* is an iron cylinder, laying in a cavity made in a hollow floater, and which may be inserted through the orifice, *g*, made in the top of the forcing vessel, and closed by a valve, *g*, kept in its position by a weight, *u*, hung on the end of a lever; *x*, a funnel through which water is introduced, and closed by a cock, *h*; the pipe, *k*, is a continuation of the forcing vessel, *f*, and is inserted in the reservoir and air vessel, *m*; *o*, a pipe conducting the water, which has been forced into the air vessel, to its destination.

The steam from the boiler, *a*, flowing through the pipe, *d*, presses the floating piston downwards, and the water beneath it is thus forced up the pipe, *k*, into the forcing vessel, *m*; when the floating piston, *s*, has reached the limit of its movement, the cock, *d*, is turned to shut off the further flow of steam into the forcing vessel, and the vapour is allowed to escape from *f*, by the cock, *e*; at the same moment, the valve, *h*, is turned, which allows the water in *x* to flow into *f*, and raise up the piston; the water in *k* being prevented from descending by the valve placed near its bottom. The opening in the lid of the forcing vessel, closed by the lever valve, *g*, *u*, is for the purpose of allowing a red-hot iron cylinder to be inserted in order to increase the heat of the steam; by the water being forced into the receiving vessel, *m*, the air which it contains is com pressed or condensed, and this is to give a greater velocity to the issuing water. This vessel was

not considered to be essential. The elector formed an engine without it, which was placed in the court of the Hessian academy of arts and sciences, that raised water into a reservoir at the height of seventy feet, whence it descended in a jet into a fountain placed in the court of the building.

Papin dedicates a division of his descriptive treatise to a comparison of the value of the elector's engine with that of his rival's; Savery's merit is acknowledged with candour, his mechanism is allowed to be effective and meritorious, and his idea to be original. With so much ingenuousness, therefore, it would be invidious to enter into a discussion, to show that the points in which the Hessian engine differed most from Savery's, were those which were the least worthy of imitation.

CHAPTER FIFTH.

"THERE IS NO ARTIST, OR MAN OF INDUSTRY, WHO MIXETH JUDGMENT WITH HIS PRACTICE, BUT FINDETH, IN THE TRAVAIL OF HIS LABOUR, BETTER AND NEARER COURSES TO MAKE PERFECT THE BEAUTY OF HIS WORK, THAN WERE AT FIRST PRESENTED TO THE EYE OF HIS KNOWLEDGE."—*Markham.*

ADMIRABLE as Savery's engine was, when compared to any thing that had been employed to raise water before its invention, many serious objections lay against its usefulness. These, however, arose more from an inherent defect in the principle of its action, than from a want of ingenuity in selecting the most proper methods for carrying the scheme into practice.

There could be no question, but that, even in the form described in Savery's book, its power was to be used at a much cheaper rate than that of animals. It was capable also of being increased and concentrated far beyond the point to which animal power could possibly be concentrated; but a short experience was only necessary to show that steam, of the elasticity used by Savery, was a dangerous agent; that on account of its expansive power, the apparatus was often deranged; a circumstance which, at the time, operated greatly against it, not only on account of the difficulty

but of the expense that was incurred in providing workmen to make the repairs; for it was not then, as now, that persons were to be had experienced in the erection and reparation of steam apparatus in every part of the kingdom.

Its first use, and location, if we may be allowed the term, was unfortunate for the inventor on another account. The fuel which was to call this power into being had to be brought from a distance. This enhanced its price, and made the comparison with animal power still more unfavourable in an economical view.

Several causes now began to be assigned for the waste of fuel. The steam, which was admitted into the cylinders, was condensed by coming into contact with the surface of the water which was to be elevated. It was observed that this water, to a small depth, required to be heated to the temperature of the incumbent vapour, before "the steam was strong enough" to expel it from the receiver. The great condensation, arising from the vapour coming into contact with the cold sides of the receiver, entered also into the general estimate of the causes of the expense of fuel. These were considered grand sources of the "great waste of steam," and it followed, of as many of coals as were burned to form it.

The attempt to obviate some of these evils was not unaccompanied with serious disadvantages. When the sides of the receivers were cooled but moderately by the effusion of cold water on the outside of the vessels, the vacuum within the cylinder was proportionably imperfect; for, unless its sides, as well as the surface of the water, were cooled sufficiently, vapour of considerable elasticity still remained, and counteracted the pressure of the atmospheric column. This, in fact,

was generally the case; for, to whatever height Savery could raise the water by the direct pressure of the steam, the action of the atmosphere was limited to raising it to twenty or twenty-one feet, before he began to force it.

In addition to these drawbacks was that of depending on the attendant for opening and shutting the cocks at the proper period. This was a fruitful source of accident, and consequently of expense, keeping its great danger out of the question; there being no contrivance, or mechanism to guard against the accumulation of steam, or prevent the risk of accident from an explosion of the boiler. It may be remarked, however, that as the boilers and pipes were usually made of copper, this, in a degree, was somewhat lessened. At this period, also, it was seldom that the engine could be used, with safety, to raise water beyond the height of thirty or forty feet, from an inability of making all the parts of a strength and solidity, which they seldom had the means of doing, and certainly not of ascertaining the fact when it was done.

It was not surprising, therefore, that these imperfections should have materially retarded the introduction of Savery's engine; nor that they should have furnished occasion to the malicious, or interested to exaggerate its imperfections, and magnify its dangers. The latter, however, seems to have been the greatest drawback on its utility; for many of the mines, which were still productive, were so deluged with water, that to extract it was so far beyond the limit of animal power, that even had steam been a much more expensive power, it must have been resorted to, had further operations been continued. It is not quite clear whether Savery introduced them into any of

the mines, or what was his general arrangement of the apparatus when he used it to pump water from depths exceeding the height of the atmospheric column. In the "Miner's Friend," he suggests a series of engines, where the mines were deep, placed at the height of sixty feet from each other; thus forcing the water only to the moderate height of forty or fifty feet, by which means the temperature of the steam could seldom exceed 216° or 220°. In particular cases, this was sometimes departed from. Desaguliers states, that he has known engines, erected by Savery long after this period, at work, when the steam was of that heat as to melt soft solder; and he also relates the particulars of an accident, which the use of it at this heat occasioned. But on the whole, considering the uncontroulable power of the agent, which may, at this time, be considered as being first called into action, the matter for wonder is, not that such casualties might happen, or did happen, but that in so short a time the powers of steam should have been applied in a manner producing so few disasters; and that too, in a state of the apparatus, in which, excepting mere strength of parts, there was no provision made for safety, or contrivances to allow the steam to escape, when it accumulated to a dangerous limit in the engine.

The project of procuring motion by the fall of a piston into a vacuum was among the earliest to which the experiments with the air-pump gave rise; and vapour was now shown to possess properties, by the medium of which this idea might probably be carried into execution. There was but one opinion with regard to the extent and convertibility of the power which might thus be created. Its regular, precise, and economical

production was the problem presented for solution to the ingenuity of practical mechanics.

In reviewing the experiments which had been made in the attempt to accomplish this grand object, it is not a little remarkable, that notwithstanding the important purposes to which its application had been suggested, so little was done towards perfecting what may be called the preliminary mechanism, by persons familiar with the projects and labours of their predecessors on this subject, and who themselves were ranked as mechanics of the highest order for forecast and invention. Dr. Hooke, one of the most ingenious and persevering mechanics that England ever produced, must especially be noticed as having evinced a surprising apathy to every thing connected with this machine. He was in the prime of life when the Vauxhall engine was in being; he knew of Papin's schemes described in the "Acta Eruditorum;" and he also knew of the fine improvement suggested in the "Recueil," (1695,) if the fact may be inferred from this book being in his library; and he could not have been ignorant of Savery's labours, in combining a mechanism to employ vapour in a different manner; yet in a letter, of which some extracts are preserved among his papers in the library of the Royal Society, the prepossession he had throughout shown against the first Marpurg schemes appears to have influenced a hasty decision also against the last; for he dissuaded an individual, who had applied to him for advice on some project for producing a first mover on this principle, from proceeding further in his experiments, as the idea was grounded on a fallacy.

Of Thomas Newcomen, the person to whom that advice was addressed, and whose name and

labours will henceforward occupy a prominent station in the history of the improvement of the steam-engine, nothing is known beyond a few particulars incidentally furnished by Desaguliers, when describing his inventions. All that can be gleaned from this source is, that he was a blacksmith, residing in the town of Dartmouth, in Devonshire; and the unimportant fact, that he was a member of a religious sect, differing in some points of ecclesiastical discipline from the national church, and on that account forming a separate communion under the denomination of Baptists. The place and time of his birth and death are alike unknown; and after the lapse of a century it were vain to hope to gratify a laudable curiosity, by rescuing even a single traditionary anecdote, either of his habits or acquirements, from oblivion. From the respectful manner however in which Dr. Allen mentions "his very good friend, the ever-memorable Mr. Newcomen, whose death he very much regretted," we may conclude that he enjoyed that rank in society, and regard of men of merit, which his admirable inventions gave him so strong a claim to; and of his colleague and townsman, John Cawley, all that is known of his history is, "that he made provision for the day that was passing over him by following the occupation of a glazier; his labours, whatever they were, have never been discriminated from those of Newcomen."

Dr. Hooke's letter to Newcomen, which has been stated as dissuading him from wasting his time and labour in any attempt to produce motion on Papin's plan, contains a very remarkable expression; remarkable, as showing his total ignorance of the rapidity with which steam was condensed by contact with a cold body. "Could he,

(meaning Papin), 'make a speedy vacuum under your piston, your work is done."

This discouraging opinion, though given by so great a mechanic, had not the effect of damping the ardour of Newcomen and Cawley; for the next time we hear of them is as having followed out the idea of producing a first motion by the fall of a piston into a vacuum made by means of steam, a scheme discarded by Hooke for being surrounded with almost insuperable difficulties.

The rough experiment differed little from that made many years before; but a slight deviation in their apparatus opened a path to the Dartmouth mechanics, which their predecessor had either overlooked or disregarded.

On a cursory inspection, this experiment varies not from Papin's*; the leading idea is unquestionably the same, yet the application and the result are totally different. In the Marpurg cylinder, the *steam* raised the *piston;* the vapour, therefore, required to be of a temperature considerably above that necessary to balance the atmospheric column. The substitution of a lever for the rack and wheel, or for the axle and ropes, was not only more convenient, but much simpler; and to the facility of raising the piston by a counterpoise, which this arrangement presented, may have been owing the disuse of high-pressure steam in Newcomen's future experiments.

This will be better understood by a reference to the diagram. The steam generated in a boiler, distinct from the cylinder, permitted these vessels to be placed permanently in the most convenient position. The piston, fixed to a rod, was attached by a joint or chain to the end of a lever, vibrat-

* P. 92, chap. iii.

ing on an axis, and the rod of a pump or other weight was fixed to the opposite extremity of this balanced beam or lever*.

The space under the piston being filled with steam, and cold water applied to the sides of the vessel, the vapour was condensed, and the column of air which rested on the piston pressed it to the bottom of the now empty cylinder. The fall of the piston depressing that end of the lever to which it was fixed, elevated the opposite end, and thus drew up the weight suspended from it. In this experiment the outline of the atmospheric engine was complete.

The power acquired by this means will be readily understood by a reference to the simplest experiments with the air-pump. A square inch of the surface of every body is pressed with a column of air which weighs about 14¾ pounds; a piston, therefore, measuring six inches on the side, or 36 square inches, is pressed with a weight of 531 pounds.

When the water in the boiler is heated to 212 degrees (Fahr.) the steam is capable of resisting this weight of air; that is, supposing a piston at the top of the cylinder, and the space under it filled with steam of 212 degrees, the piston would remain in its position; if the steam were raised to 214 degrees it would be raised out of the cylinder. But if the vapour beneath it was only 208 degrees, the piston would move downwards; that is, "the elastic force of the vapour of this heat would be too weak to resist the weight of air pressing on the piston."

If, as has been already described, the steam in the cylinder is heated to 212 degrees, the pis-

* See vignette, p. 139.

ton will be supported by it, or prevented from falling downwards; but if cold water be applied to the sides of the cylinder, and the steam within it *cooled*, or condensed into water, it is obvious that the entire space which the steam occupied (deducting that which is filled by the water into which it has been converted) is a *vacuous space*, or the cylinder contains nothing able to resist the great weight of air laying on the piston; that body, therefore, *falls* into the cylinder in the same manner as a piece of iron weighing 531 pounds would do; and, by using proper intermediate means, is capable of performing the same effects that a piece of iron or other body of this weight can effect which falls from the same height that the piston fell in the cylinder.

That is on the supposition that the motion of the piston in the cylinder met with no retardation by rubbing or sliding along its surface, and that the balanced beam moved on its axis without experiencing any resistance; but in practice the case is widely different. Even when the inside of the cylinder is finely polished, and truly circular, and the sides of the piston made to work into the circular vessel with precision, and the balanced beam to move freely on its axis, a considerable resistance is offered to the descent and rise of the piston, and to the vibration of the beam by *friction*. In this simple mechanism it would probably require forty or fifty pounds' weight to be hung at the extremity of the beam to raise the piston from the bottom to the top of the cylinder, supposing steam of 212 degrees was admitted to flow into the space as the piston rose. This power would therefore be considered as lost, because it is expended merely in moving the machinery; at this time another portion of the power,

or weight of air, on the piston, was generally absorbed in consequence of a want of means to form the cylinder and piston perfectly true; and, when the vacuum was produced, the air insinuated itself into the spaces left by the inequalities of the work under the piston, and, of course, prevented its descent. The edges of the piston were therefore packed or fitted with some substance, which was elastic, and receded and expanded from protuberances, and into spaces, during the motion of the piston. Hemp was often used for this purpose; sometimes, say the authors of the time, *leather* * was tried; with both tallow was used, as well to lubricate the surfaces as to fill up the pores of the packing, and a quantity of water was also allowed to lay upon the top of the piston.

The complete condensation of all the steam under the piston was another circumstance essential to the developement of the full power of the mechanism: if this were not accomplished, the vapour that remained resisted the weight of the atmospheric column in proportion to its temperature. The effect of this was to diminish the amount of weight that could be suspended from

* "About the year 1717, I communicated to Mr. H. Beighton, the use of the steel-yard over the puppet-clack or safety valve, which he applied to some engines. The way of leathering the piston was found by accident, about 1713: having then screwed a large broad piece of leather to the piston which turned up the sides of the cylinder two or three inches, in working it wore through, and cut that piece from the other, which falling flat on the piston wrought with its edge to the cylinder, and having been in a long time was worn very narrow, which being taken out, they had the happy discovery, whereby they found, that a bridle-rein, or even a soft thick piece of rope or match going round, would make the piston air and water tight." Desaguliers' Experimental Philosophy, p. 333. vol. ii.

the pump-end of the beam; that is, if the vapour remaining in the cylinder had a temperature which would resist a column of air equal to three or four pounds on the square inch, so much, of course, was deducted from the total pressure of air on the cylinder. The *air* itself had also an effect in preventing the fall of the cylinder, even when it was prevented by the usual means from finding its way into the vacuum between the sides of the receiver and the piston. The water from which the steam was generated contained more or less air, which boiling disengaged; this entered with the vapour into the vacuum; the steam with which it was mixed could be condensed, but air could not, and it remained in the cylinder, and prevented, by its greater or less action, the fall of the piston, by filling the space under it: from this cause alone, (and which was afterwards known by the term of *wind-logged*,) this engine must have soon ceased its motion. This defect could seldom be very apparent in Savery's apparatus, and a *small* quantity of air always laying in his receivers would be rather an advantage than otherwise, as it would prevent the cold surface of the water from condensing the vapour; and, lastly, the new *form* of the steam cylinder, which now required to be open at the top and perfectly cylindrical, and placed perpendicularly, was exceedingly unfavourable for permitting the vapour to be condensed, as Savery did it, by an affusion of cold water *on* the outside of the vessel; indeed his scheme would have been nearly impracticable with Newcomen and Cawley's apparatus.

The defects of this rough experiment have been enumerated at a greater length than their importance may seem to demand, but as it is only in the first stage of the invention that the steam cylinder

of Papin can be brought into the comparison, it appeared but fair that the peculiarities of each should be even amply displayed: for on the whole, although Papin may be certainly considered as the author of the mode of elevating a piston by steam, and afterwards condensing the vapour, his labours beyond the first step could offer but small assistance to Newcomen and Cawley.

The difference that the use of a lever probably made in the experiment of Newcomen has been already stated. The pipe by which Papin supplied his cylinder with water, also served as a pipe by which the air which was disengaged from the water escaped from under the cylinder.

These ingenious persons had, however, a rival to propitiate, who claimed the invention of a part of the mechanism*; and the individual who urged this claim, was not only a man of enterprise, but had both the influence and means to maintain his pretensions; and without his concurrence, Newcomen and Cawley found it impossible that their scheme could ever be carried into practice—Captain Savery was in possession of the right to use the *method of making a speedy vacuum by condensing Steam;* and in the grant of an exclusive privilege

* "As the best and most useful inventions and improvements, which have been discovered either in art or nature, have in the process of time been subject to the same, so this ingenious gentleman, (Mr. Newcomen,) to whom we owe this late invention, (the Fire-engine of Savery,) has, with a great deal of modesty, but as much judgment, given the finishing stroke to it. It is, indeed, generally said to be an improvement on Mr. Savery's engine; but I am well informed that Mr. Newcomen was as early in his invention as Mr. Savery was in his, only the latter, being nearer the Court, had obtained his patent before the other knew it; on which account Mr. Newcomen was glad to come in as a partner to it."—Vol. ii. p. 216., *Switzer's Hydrostatics.*

for the new engine, his interest was consulted by associating his name with that of Newcomen and Cawley in the patent. But in their future operations, we so completely lose sight of Savery, that it were great injustice to these ingenious men to suppose for an instant that he did any thing but receive his share of the profits of the speculation.

From the moment that Newcomen and his colleague found themselves clearly in possession of the principle, their most assiduous care appears to have been exerted in removing the imperfections of their apparatus; and one deficiency which they supplied in a very early stage was a means to condense the steam without throwing cold water over the vessel, as in Savery's engine. This was an object of great practical importance, as it is extremely probable that the boiler was, in the very first attempts (as it continued to be for nearly fifty years afterwards,) placed beneath the cylinder; and in this arrangement it obviously was impossible so completely to protect the top of the boiler from being splashed by the water thrown on the cylinder, as to prevent a condensation of the steam with which it was filled, and which it was essential to preserve at a high temperature.

Instead of throwing cold water on the cylinder, *c*, as in the diagram, Newcomen surrounded that vessel with cold water, and by this means every part of the surface was exposed to the cooling influence. The steam cylinder was thus placed as it were within another, and the space *x*, between them contained the condensing medium. (Figure marked NEWCOMEN, A.) But short experience would show, that this contrivance could only be practised with effect under certain circumstances. The practical inconvenience

which resulted was, that the water which cooled the steam, itself became heated in the process, and was thus unfit to produce the effect which it was introduced into the concentric space to perform. It was also necessary that, when the cylinder was filling with steam, the space between it and the outer vessel should either contain water, nearly of the temperature of the steam within, to prevent condensation, or it should be entirely empty. Means, therefore, were to be taken to supply *cold water* with *great* rapidity when the condensation was to be produced, and, of course, to withdraw with equal rapidity that portion which had become heated by its contact with the hot cylinder.

The cistern for the cold water, *m*, (in the figure marked NEWCOMEN B.) could not be more conveniently placed than over the cylinder, and a pipe, *n*, conducted the water from it into the space *x*, formed by the casing. Another pipe, *h*, conducted that which had become heated into the reservoir, *k*.

The steam which was condensed, and the injection water, formed within the cylinder a quantity of hot water, which, although of small bulk when measured after one or two condensations, quickly accumulated beneath the pistons when the machine was in action, and would, by its doing so beyond a certain limit, entirely stop its motion. To carry this off, a pipe, *i*, was inserted into the bottom of the cylinder, and conveyed downwards, and its end was inserted into a cistern, *y*. In adjusting this pipe, attention was also to be had to *the pressure of the atmosphere;* for unless it were of sufficient length, as it communicated with a vacuum, formed at each stroke under the piston, the water would be forced *from the cistern into the cylinder* instead

of falling from it. This pipe was therefore made to descend to a depth of about 30 feet below the bottom of the cylinder.

Still the air, which might find its way into the cylinder by the sides of the piston, or which, rising from the water into the boiler, mixed with the steam, was disengaged when the vapour was condensed, was also to be extracted from this vessel; this is found in the very earliest engines to be done by placing a pipe, *s*, at the lower part of the cylinder, and opening into the atmosphere, having a valve placed at its extremity, opening upwards, and inserted in a sort of cap, containing water. The descent of the piston compressing the air, made it raise this valve*, and as soon as it had escaped, the water which lay over it sufficed to make the valve air-tight. Some authors state that this air was expelled along with the water through the descending pipe, but this must have been in all cases inconvenient, and in many impracticable.

A stream of water was also allowed to flow upon the piston, in order, by interposing a denser substance than air, to make the piston still more air-tight than it could be by the packing.

The junction of the *boiler* and *steam-cylinder* was made by a pipe *t*, proceeding from the top of the one, and inserted into the bottom of the other, having a cock, *e*, to interrupt the flow of steam at pleasure. And the height of the water in the boiler was ascertained by the same means that Savery had adopted,—using two pipes of different lengths, which he called *Gauge pipes*, 2.

* "This is called the sniffing valve, because the air makes a noise every time it blows through it like a man sniffing with a cold."—p. 474. vol. II. Desaguliers' *Experimental Philosophy*.

It has already been observed, that from their first trials, Newcomen and Cawley operated with steam, whose temperature never exceeded that of boiling water; and the vapour was used strictly *as a means of forming a vacuum*. The weight of the piston, its friction, and the friction of the axis of the balance-beam, and the resistance of the pumps, had, therefore, to be overcome by other means, and the *counterpoise*, *w*, was an effective and obvious one; this was a weight, hung on the balance-beam, generally on the pump-rod, as shown in the figure.

The operation of this improved apparatus is very simple. When the water has been raised to the temperature of 212 degrees, and the cavity of the boiler filled with steam, the cock, *e*, is turned, and a communication is thus opened between the cylinder and boiler; and the counterpoise draws the piston to the top of this vessel. When the piston is in this position, the cock, *e*, is turned to its first position, and the further flow of steam is prevented. Cold water is now allowed to fall through the pipe, *n*, proceeding from the cistern into the space between the cylinders, and filling it, condenses the steam under the piston; the weight of air resting upon it, presses it downwards into this vessel, which elevates the weight on the other end of the beam, or the water in the pumps. When the piston has reached the bottom of the cylinder, or as it is termed, made its stroke, the steam-cock is again opened, the cistern-cock shut, and an equilibrium being thus restored between the two sides of the piston, the counterpoise as before acts to pull it to the top of the cylinder, and the apparatus is again ready to make another stroke. At the instant when the piston has nearly arrived to the limit of its stroke,

and before the steam-cock is opened, the cold-water pipe is shut, and the cock *h*, permitting its fall into the cistern, opened, so that when the steam was admitted into the cylinder, the annular space was empty. In another arrangement, the water which had been heated by the previous stroke was allowed to remain, until the piston had been raised nearly to its limit; it was then allowed to flow into the reservoir, and was replaced by the cold water from the cistern. The water arising from condensation escapes by the pipe, *i*, and the air by the other pipe, *s*.

The waste of water in the boiler by evaporation was supplied by Newcomen in a simpler manner than in Savery's engine; and part of the heat which was lost by the condensation of the steam in the Captain's machine, was saved by replenishing the boiler with the water which had been heated between the cylinders; by conducting it into a pipe rising from the boiler, or pumping it into this pipe from the reservoir, into which the heated water fell both from the inside and outside of the cylinder.

It were almost superfluous to notice the prodigious difference in safety between this machine and that of Savery; and to point out the variety of situations, in which the lever engine must be a more convenient agent than its rival apparatus. But there were circumstances demanded in the construction of the one, which were not essential in the other, which were greatly in favour of that the most deficient in principle.—One of the greatest objections attached to Newcomen's apparatus, was the accuracy of workmanship which was demanded in the *construction* of the cylinder and piston, and which could not be obtained by any of the mechanical means then resorted to:

this, added to the imperfect vacuum, that could only be formed by the cooling of the outside of the cylinder, made Newcomen's, in the comparison, a much less effective machine than Savery's, and quite as expensive. The opening and shutting of the cocks by hand practised in both, made them equally inconvenient in this respect, but still the advantage lay with Savery; for inattention on the part of the attendants was not productive of so much irregularity as with the lever engine —this last requiring a degree of precision, much greater than was demanded by the other.

Desaguliers relates that, in 1711, an offer made by Newcomen, to drain water from a mine at Griff, in Warwickshire, was not accepted, from a doubt as to its practicability; but that in the succeeding spring, Newcomen succeeded, through his friend, Mr. Potter, of Bromsgrove, in Worcestershire, in getting a contract to draw water from a mine belonging to a Mr. Back, at Wolverhampton*. The account of their first trial is curious, as exhibiting the difficulties the inventors had to cope with, even after the machine was invented; although carried into execution in a rough way, it was still far from being in a state able to realize even moderate expectations. "After a great many laborious attempts, having at last made the engine work, but not being philosophers enough to understand the reasons, or mathematicians enough to calculate the powers and proportions of the parts, they very luckily found by *accident* what they sought for.—They were at a loss for the pumps, but being so near Birmingham, and having the assistance of so many admirable and ingenious workmen, they soon came to the method of

* P. 533. vol. ii. Experimental Philosophy.

making the pump, valves, clacks, and buckets, whereas they had but an imperfect notion of them before*."

The erection of this machine led to an improvement which added prodigiously to its power, as well as to the uniformity of its operation. The usual manner of condensing the steam by cooling the cylinder was not so effective in practice, as at first sight it might appear to be, the *vacuum* produced by this means was exceedingly imperfect; a defect in their apparatus, the existence of which was cautiously guarded against, as being a great aggravation of this defect, led not only to its entire removal, but to the simplification in no ordinary degree of the general mechanism of the engine. It was of essential importance to the action of the piston, to keep the cylinder beneath it free from air, and to guard in the most effectual manner against any gaining admission by the sides of the piston: for this purpose, a quantity of water was kept laying upon it, which was from time to time renewed from the cistern by a cock and pipe†. On the first trials of this engine, the inventors were surprised to see it "go several strokes, and very quick together; when, after a search, they found a hole in the piston, which let the *cold water in to condense the steam in the inside* of the cylinder, whereas before they had always done it on the outside."

This fortunate discovery led to the mode of *condensing the steam* by an *injection* of cold waste inside of the cylinder, instead of doing the same thing by cooling the surface of the outer vessel; and this also suggested a method of regu-

* P. 533. vol. ii. Experimental Philosophy.
† See p. 155.

lating the speed of the apparatus, when the weight on the pumps was variable, or the engine working against a resistance beneath its power: a larger or a smaller quantity of injection water thrown into the cylinder, produced a less or a more perfect vacuum.

In the figure (marked NEWCOMEN, B.), the parts remain as before, but instead of the water flowing into the concentric space, the vessel which formed it was dispensed with, and a pipe, *n*, and cock, *p*, (called the *injection pipe* and *injection cock*,) proceeding from the cistern, was inserted into the bottom of the cylinder. When that vessel was filled with steam, turning the injection cock, *p*, allowed a jet of cold water to rise through the vapour: by this means the condensation, when compared with the other process, was *complete* and *instantaneous*. The greater quantity of water which had now to be removed from the cylinder was taken of by the *syphon pipe*, *i*, as before; and the air which was introduced by the same means, also escaped from the pipe, *s*, as already described in the explanation of the previous figure.

There is now no means of ascertaining what progress was made in introducing Newcomen's engine into practice. Bradley incidentally mentions one belonging to a Mr. Louder, of Newhaven, which was a considerable improvement on Savery's invention.

The same writer describes one made by the *late* Mr. Savery, and erected by the inventor about 1712 for "that curious gentleman Mr. Balle, at Cambden-house, which has succeeded so well, that there has not been any want of water since it has been built; and for the improvement of the curious" he gives a design of it, "which he thinks the

truest-proportioned of any about London:" this forms the subject of the engraving (marked SAVERY, M.), "*b*, a boiler containing 39 gallons, *e*, a receiver holding 13 gallons; the pipe, *g*, from the surface of the water to the engine-tree, *f*, is 16 feet, which is the length that it sucks the water, but it may be made to draw the water 28 feet; the engine-tree, up to the great cistern which receives the water, is 42 feet, but might be a hundred feet high if such a quantity of steam be allowed as is proportionable to the length of the pipe. The diameter, as well of the *sucking pipe*, *g*, as of the *force pipe*, *l*, is 3 inches; of the steam pipe, *d*, about an inch. When this engine begins to work, you may raise four of the receivers full of water in one minute, which is 52 gallons, and at that rate in an hour's time may be flung up about 3120 gallons, which is above 6 barrels—or if there were two receivers, one to suck while the other discharged itself, as has been practised, we might raise 6240 gallons in the same time. The prime cost of such an engine is about 50 pounds, and the quantity of coal required for each working is about half a peck, so that the expense will be very trifling in comparison to what the carriage of water upon horses would amount to; and in such countries where wood is plenty, would amount to much less."

Some of these machines were erected of considerable dimensions. For Bradley* further informs us that he had seen an engine, with two receivers, which held each of them a barrel (36 gallons) of water, which would furnish so great a quantity that

* P. 178, vol. ii. *New Improvements of Planting and Gardening*, both philosophical and practical, by Richard Bradley, F.R.S. 1718.

even some tolerable large fountaine were supplied by it*.

The action of this mechanism being precisely the same as that which has been described before, it will hardly be necessary again to explain its operation: *b*, is the boiler, *n*, funnel to supply it with water, *c*, handle of cock, which shuts off and admits steam, *d*, pipe connecting receiver, *e*, and boiler, *f*, a box or engine-tree connecting the rising and eduction pipes; *o*, reservoir. In this it will be seen the condensation is produced by water falling on the outside of the receiver as described in the MINERS' FRIEND.

For the next important improvement, on the same part of the machine, we are indebted to a boyish love of idleness and play. "It was usual to work with a buoy in the cylinder, enclosed in a pipe, which buoy rose when the steam was strong, and opened the injection pipe, and made a stroke, whereby they were only able from this imperfect mechanism to make six or eight strokes in a minute, till a boy named Humphry Potter, who attended the engine, added what he called a *scoggan*†, a catch that the beam or lever always opened, and then it would go fifteen or sixteen strokes in a minute‡."

* P. 179, vol. ii. *Ibid.*

† *Scog*, a term in use in the north of Scotland for that part (made with hair) of fishing tackle to which the hook is fastened. *Scogie*, a drudge. Another derivation has been suggested from *to scog*, to hide or secrete. *He's scugging* is a phrase for one avoiding his pursuers: A correspondent in the *Mechanics' Magazine*, p. 154, says, that to be found *scogging*, to be a *scogger*, are terms in very common use in the north of Yorkshire, and convey exactly the meaning of the terms, to be found skulking, to be a skulker. By a slight corruption *scoggan*, as the operation which is performed enabled the boy to be *scogging* instead of attending to his business.

‡ P. 178. vol. ii. Desaguliers' Exper. Philos.

A short man, extremely near-sighted, with very irregular features, fat, squabby, and lumpy in his limbs, ungainly, awkward, and shuffling in his gait, is the picture drawn of the personal appearance of the celebrated Doctor Desaguliers:—at once an engineer, contractor, clergyman, lecturer, smoke-doctor, and farmer, and standing in the very highest rank among those philosophers, to whose genius and perseverance we owe the magnificent structure of experimental physics. He was born at Rochelle, but when he was not more than two years of age, the flight of his father, a protestant clergyman, from France, after the revocation of the edict of Nantes, made England become the country of his domicile. He studied and read lectures at Oxford, until he married and came to London, where he first introduced the reading of popular lectures on philosophy. But his great talents, and the patronage which followed them, did not preserve his old age from want. The money-making, kind-hearted, but improvident Desaguliers fell into miserable poverty. In his youth and middle time, his habits were temperate, approaching even to abstemiousness; yet in his old age he became not only distinguished as an epicure, but blamed for his gluttony; and life closed upon this friend of Newton, this preceptor in philosophy to kings and princes,

> "In a cell without a friend to save,
> Without a guinea, and without a grave."

To his industry we owe nearly all the information we possess, of the early history of the steam-engine. But his claim to an improvement on it must however form an exception to his general merit.

In his Experimental Philosophy he relates—"when Doctor S'Gravesand, who had come over

to England as secretary to the Dutch embassy, and himself, were considering Savery's fire-engine, as it is described in Harris's Lexicon Technicum, it appeared to them that there was a great waste of steam, by its continually acting upon the receivers without intermission; it becoming useless until it had heated the surface of the water in the reservoir, and also to a certain depth; they thought that were it so contrived, that after the steam had pressed up one receiver full of water, instead of being thrown upon another, it should be confined in the boiler, till the reservoir (or receiver) was refilled by the atmosphere, and then turned upon the water; that by this means its confinement might give it so much force, that it would push hard against the surface of the water, and have discharged a great deal of it, even before it had heated the surface; and that Savery had perhaps, in his great work, chosen to use two receivers, because the Marquis of Worcester mentions two in his account. They resolved to have a working model made to act either with one or two receivers. This model soon showed then, that one receiver could be emptied three times, whilst two succeeding ones could be emptied but once each; so that by this means an engine would be so simple, as to be more easily worked, cost almost half less, and raise a third more water*."

* "Another engine which I put up for a friend twenty-five years ago, drew up the water twenty-nine feet from the well, and then it was forced up by the pressure of the steam twenty-four feet higher, into a cistern holding about thirty tons, set up at the top of a tower in order to run down again through a pipe of conduct, and play several jets in the gardens.—But sometimes no jets being played, the water was, at the height of five or six feet, discharged out of the force pipes to fill the ponds, and water meadows in dry weather, which it did with a less strength of steam than what drove the water

The reason here given by Desaguliers for Savery's preference of two receivers, is on a par with his invention. And if Savery had not such high pretensions to philosophical acquirements as Desaguliers, his observation and tact had taught him, by proportioning the size of his boiler to the capacity of his receivers, to avoid the error into which his rival appears to have fallen in the construction of his machines. The Doctor would have produced the same effect by enlarging his boiler, as by withdrawing a receiver. And Desaguliers' improved engine is, in fact, but a *lame copy* of one erected by Savery himself years before*. There are two peculiarities to be found in this mechanism, however, which are not observed in any before this date; the mode of condensing the steam by an injection, as used in Newcomen's apparatus, is transferred to this, with probably an improvement. The *injection pipe* and the steam pipe are separated by a cock similar to that used by Doctor Papin in his air-engine, so that when, by turning the handle, the steam is shut off from the receiver, the injection pipe is open, and this water is made to fall through a

into the tower, or if the same strength were kept up, one might make eight or nine strokes in a minute, instead of about six, when the water was driven up into the cistern. Upon the safety valve there was a *steel-yard*, the place of whose weight shows the strength of the steam, and how high it was capable of raising water; but when the weight was at the very end of the steel-yard, the steam then being very strong, would lift it up and go out of the valve rather than damage the boiler."

"About as much fire as a common parlour fire was sufficient to work this engine, and to raise fifteen tons per hour. This engine, according to *my method*, (?) consists of so few parts, that it comes very cheap in proportion to the water that it raises: but it has its limits.—P. 214, vol. ii. Experimental Philosophy.

* See p. 160.

cullender in order to distribute the injection more equably. A *safety valve* is also placed on the boiler.

In the description of Savery's first engine, it was observed that there was no contrivance for safety; but if, as it is probable, that in the machine described in his *Miners' Friend*, there was always a communication open between his larger boiler and one of the receivers, this at all times would operate as a safety valve, of a sort the least likely to be out of order. In this engine by Desaguliers, however, from the use of the four-way cock, instead of the *sliding valve*, this appendage was indispensable; and it was probably with an engine on this construction that the accident occurred, which is so often appealed to by succeeding writers*.

About 1717 these engines were introduced into Russia. "The first was made by Desaguliers for the Czar Peter I., for his garden at St. Petersburgh. The boiler was made spherical, as they must all be in this way where the steam is much stronger than the air, and held between five and six hogsheads: the receiver held one hogshead, and was filled and emptied four times in a minute. The water was drawn up by the suction or pressure of the atmosphere twenty-nine feet high out of the

* "About three years ago a man who was entirely ignorant of the nature of the engine, without any instruction, undertook to work it, and having hung the weight at the farther end of the steel-yard, in order to collect more steam to make his work quicker, having also a very heavy plumber's iron upon the end of the steel-yard, the consequence proved fatal; for after some time, the steam not being able, with the safety clack, to raise up the steel-yard, loaded with all this unusual weight, burst the boiler with a great explosion, and killed the poor man who stood near, with the pieces that flew asunder, there being otherwise no danger by reason of the safety valve, made to lift up and open upon occasion.—p. 214. *ibid.*

well, and then pressed up about eleven feet higher. The pipes were all of copper, but soldered to the horse with soft solder, which he knew would hold very well for that height, or a greater height for that quantity, for if the quantity was larger, then the boiler must be greater, and the steam of the same force would have a greater surface to act upon, which might burst the boiler or require it to be made thicker."

CHAPTER SIXTH.

"OFTENTIMES AN UNCERTAINTIE HINDERED OUR GOING ON SO MERRILIE—BUT, BY PERSEVERING THE DIFFICULTIE WAS MASTERED, AND THE NEW TRIUMPH GAVE STRONGER HEART UNTO US."—*Raleigh.*

THE manner of condensing the steam by injection, of removing the water and air which were produced in the process, of keeping the piston air-tight by water laying upon its surface, supplying the boiler with hot water, and elevating the piston by a counterpoise, exhibited in this early stage of the invention, have been found by subsequent experience to be all the parts essential to the effective operation of the apparatus of Newcomen. The minor details remain in a rude artificial state, both as to construction and arrangement.

It will in particular be noticed that the most important movement of the machine depended, not only for its production, but what was almost of greater consequence, for its precision, upon the care and attention of the person who attended the engine. And when were call to remembrance what was the nature of the object of this attention, it will be no matter of surprise, that the most unremitting care fell greatly short of that demanded for

the perfect developement of its power. When, for instance, the attendant opened the steam cock, he was obliged to watch the ascent of the piston, and at the instant when it was elevated to the proper height, it was to be again quickly shut, and at the same moment, the injection cock was to be opened: if the one did not follow the other, there resulted a great loss of vapour, or of effect; and this difficulty was further increased by the irregular production of the steam itself from the varying intensity of the heat of the furnace. After the injection had condensed the steam, and the piston was at liberty to descend, if the communication between the boiler and the cylinder were not opened at the precise instant when it had reached the limit of its downward movement, the immense weight on the piston, falling into the vacuum with a great velocity, would shake the apparatus to pieces. All this precision was required, too, from a mercenary attendant, fourteen times *every minute*, at a hazard of the total destruction of the apparatus, if his attention were attracted from his employment so long only "as to observe one wag of a spaniel's tail." A regular series of simultaneous movements, it will be seen, were totally out of the question, for whatever improvement was attempted in these series of catches and strings, one end of them was always in the hand of the engine-man or cock-boy.

Humphry Beighton, an individual of great experience and practice as an engineer, among the mining adventurers in the north of England, had numerous opportunities of observing the inconveniences and defects of the common apparatus; and, in an engine which he erected in 1718, at Newcastle-upon-Tyne, he made a successful attempt to remove them. The parts he added were named

hand gear, from their supplying the place of the catches and strings hitherto moved by the attendants, and consisted of a rod suspended from the balanced lever or beam, which by tappets acted on levers attached to the injection and steam cocks, and opened and shut them, as they might be adjusted.

The *valve* by which the flow of steam was shut off from the cylinder, was of the same form with that used by Savery, and called a sliding valve, and was also placed inside the boiler. The *injection cock* did not differ from the sort in common use.—See figure marked BEIGHTON.

The axis or spindle, *a*, of the sliding valve, *c*, projected through the roof of the boiler, and a lever, *b*, was fixed to it. This was attached to another lever, *d*, having its opposite extremity, *e*, formed like a *fork*, and the two *prongs*, *f*, *g*, connected by a wire. This wire, *i*, in its turn formed the axis, to which was attached two pieces of iron, called the stirrup, *o*, *m*, fixed on an axle, *s*; between these two pieces, also on the same axle, was fixed the Y piece, so called from its resemblance to that letter, reversed; and had a weight placed on the stalk: this appendag was named the *tumbling bob*. The spanners, *x*, *y*, were also fixed on this axle: and were so placedas to be moved upwards and downwards by tappets fixed in a rod, *s*, suspended from the balanced beam.

The toothed quadrant, *p*, fixed on the axis of the injection cock, was moved by another quadrant, *r*, attached to a lever, *p*, also acted upon by projecting pins or tappets fixed in the plug-frame. In the engraving the forks are shewn in a position as if the injection cock was open, and the steam valve shut; and that the piston has approached near to the bottom of the cylinder. The fall of the

plug frame makes a tappet strike on one of the arms of the spanners, which turns the axle, and by this means raises the *tumbling bob* beyond the perpendicular, and the weight causes it to fall with a considerable force in the other direction—one of its prongs pressing upon the axis of the stirrup, pushes it forward, and moving the lever, opens the steam valve. At the same instant that the tappet moved the spanner, the tappet, 2, pressing upon the lever of the quadrant, shut the injection cock, and the piston now being in equilibrium, the counterpoise draws it upwards. When it has nearly arrived at the top of the cylinder, the tappet, 3, in the plug frame, also rising, strikes the spanner—this turns the axle. The Y piece is by this means again turned into the opposite position, and the weight of the *tumbling bob*, making it fall with a considerable velocity, the prong draws the fork into the former position, and the steam cock is again shut. The tappet during this operation has also depressed the lever, and shut the injection cock; and this operation may obviously be repeated as often as it may be necessary.

This apparatus does not differ essentially from that given by other authors; but Desaguliers, who describes it in 1743, may have unintentionally given a form of it more perfect than it possessed at the period of the erection of the Griff engine. But at all events, by its introduction, the atmospheric engine, for the first time, became a self-acting machine.

The engraving (marked NEWCOMEN, F.) will suffice to give a general idea of the appearance of this machine, until the experiments of Smeaton. It is described and figured by Desaguliers, in his book which was published in 1743; *a*, is the boiler; *b*, steam-pipe; *c*, cylinder; *d*, injection-

pipe and cock; *e*, its lever; *f*, the horizontal fork; *g*, the stirrup; *h*, the axis of the tumbling-bob; *i*, *k*, the plug-frame, with the tappets, *l*, *m*, *n*; *o*, sniffing-valve; *p*, eduction-pipe for condensed steam and injection water; *q*, gauge-cocks, *r*, safety-valve, or puppet-clack; *s*, pipe for supplying water to boiler; *t*, pipe from cup of the cylinder; *u*, pipe for waste water which was raised by piston; *v*, pipe from cistern; *w*, fire-place; *x*, piston-rod and chain; *y*, working-beam.

Steam being raised in the boiler, *a*, it flows through the pipe, *b*, into the cylinder; this produces an equilibrium between the upper and under sides of the piston, and it rises to the top of the cylinder by the weight of the counterpoise placed at the opposite end of the lever-beam. By its ascent the plug-frame is also raised, and one of the tappets, *l*, *m*, *n*, which are fixed into it, striking upon the end of the lever, *e*, fixed to the loaded quadrant, opens the injection-cock, *d*; a jet is thus introduced into the vapour which condenses it. At the time when the tappet struck on the lever of the injection-cock, another struck one of the spanners, and by this means, turning the axle on which it is fixed, the tumbling-bob is carried into the opposite position, and one of its prongs being thus made to act on the axis of the stirrup and horizontal fork, the lever attached to the steam-valve is thus drawn forward, and the flow of steam from the boiler is prevented. The tappets are so adjusted, that the steam-valve is perfectly shut, before the injection-cock is opened. The fall of the piston, by the pressure of the atmosphere, reverses all these motions—shutting the injection-cock;—opening the steam-valve by the action of other tappets; and thus a tolerably regular series of reciprocating motions is produced.

A simpler method than either of these, of opening the steam and injection cocks is described and figured by Leupold, as practised in a German engine, constructed by one Potter an Englishman, previous to 1724. The engraving marked NEWCOMEN, exhibits this contrivance: *m*, the plug-frame, or the perpendicular rod attached to the beam; *k*, the end of a lever moving on an axis, *h*, having a fixed piece, or staple, perforating the roof of the boiler, and pressing on the end of another lever, *g*. within the boiler, which has its other extremity, *f*, so constructed, as to close the orifice of the steam-pipe when it is raised into the proper position; the *injection cock* is opened and shut by means of a jointed lever, connected with the lever, *k*. The manner of its action will readily be understood from an inspection of the engraving.

The second figure in the same engraving shows the method in which the counterpoise was employed, which raised the pump-buckets in the same engine; *n*, the pump-rod attached to the lever-beam; *k*, a small lever-beam; *i*, the counterpoise.

In the engine described by Desaguliers, as well as that shown in Leupold's book, the *buoy*, which in the earlier engines, rose and fell, and opened the steam-cock, does not appear; from the notice of the improvement made upon it by the use of a scoggan, and its absence in the machines which have just been detailed, it might be inferred, that the mechanism had given place to more perfect methods—but from an exceedingly rare and curious print, published in 1725, it is shown as then used in some engines. This engraving, it is true, may have been made from an engine constructed long before; but, on the other hand, it is

improbable that so much care would be taken in describing a mechanism, which was either considered to be obsolete, or not on the most improved construction then in use:—as it is the only one which we have met with in which the *buoy* is described, the detail of its parts are interesting, as filling up a step in the progress of invention, will be given at length.

In the figure (marked NEWCOMEN, 1725,) *a*, is the fire-place, *b*, the boiler, *c*, piston, *d*, steam-pipe, *e*, axis of the regulator, or steam-valve, *d*, steam-pipe, *f*, a loaded or safety valve, "which gives vent to the steam of the boiler in case it grows too strong; *g*, gauge cocks with their pipes, one of which goes down so far into the boiler, as to be two or three inches above, and the other so far below the surface of the water therein," the water being of a due height when the steam is emitted by the shorter, and water by the longest pipe; *h*, a pipe fixed to the head of the boiler, and called the *buoy* pipe, open at both ends, the lower end being a foot or more below the surface of the water in the boiler. Within this pipe is a cylindrical buoy that swims upon the water therein; and when the steam in the boiler is become so strong as, by its pressure, to force water up the said pipe, it then raises the buoy, whose axis, 12, causes the *balance*, *r*, and *inceptor*, 7, also to rise, and lifting the *notch*, 2 from 3, on one end of the lever, permits 13, a weight attached to it, to fall so far, till the *injecting-cock* at *n*, the axis of the said lever, is opened, by which an injection of cold water from the cap of the injection-pipe being made, and consequently a vacuum by the condensation of the steam; the pressure of the atmosphere brings down the inner end of the great lever, when one of the pins in the hanging-beam,

q, takes hold of 1, the end of lever, *o*, which by the fall of weight 13, at the other end of it, was raised as above, somewhat higher than the parallel of its axis at *n*, and brings it down so far till the end, 3, is raised up as high, as to be again taken hold of by the notch 2, at which time the injection-cock is thereby shut, and the regulator, *e*, is opened; *k*, a pipe for supplying boiler with hot water from top of cylinder; *l*, piston, having always eight inches of water lying upon it; there is a "circular plate in diameter nearly equal to the cylinder, and closed thereto, with leather round the edge;" *m*, injecting-pipe, *n*, injecting-cock, "with its wheel, which is opened and shut by *o*, a small lever and its quarter-wheel, whose ends 1 and 3 are alternately lifted up by the engine's motion;" "*p*, an axis moving between two standards, with its shanks, 4. 5. 6. 8. 9. and a slider 10:—*q*, beam (or plug-frame)" hanging on the great lever, and moving up and down with it, opens and shuts the regulating and injecting cocks by three pins, set higher or lower as occasion requires it; one of which pins as the beam is going up, upon the access of the steam into it, takes hold of 8, attached to axis, *p*, and raises it to such height, till the weight 14, on lever 9, gets beyond the perpendicular of its axis, when by its own gravity it falls so far toward the cylinder as the piece of leather, 15, will permit it, by which motion the wire 5, the end of which appears in the draught at a pin in the slider 10, is removed, and lever 4, is brought down to take its place, and striking against this pin, carries it away so far, and with it the slider, till the regulator at *e*, to whose handle the slider is fixed, is by this means shut, and the steam confined in the boiler—by the same motion the lever 6, (shown in the engraving,

slanting downwards,) is raised somewhat above the parallel of the axis, *p*, and lies ready to be taken hold of by another pin in the hanging-beam, *q*, which upon the condensation of the steam, brings down this lever so far, till the weight, 14, is again brought beyond the perpendicular of the axis, *p*, on the other side, when by its own gravity, this again falls beyond the perpendicular of its axis on the other side as the piece of leather will permit; by that motion the lever, 4, is again removed from the pin in the slider, and the lever, 5, is made to strike against it, which opens the steam-valve.

The steam now having a free passage out of the boiler into the cylinder, and the pressure upon the surface of the water being abated, the *buoy* in the pipe, *h*, falls, and with it the balance, *r*, and inceptor, 7, and the notch, 2, takes hold of the end, 3, of the lever, *o*, by means of which the injecting-cock remains shut, as has been previously described, so that the steam by its force against the bottom of the piston countervails the pressure of the atmosphere, and permits it to rise along with the hanging-beam, *q*, which, by the action of the pin, shuts the regulator, when the steam being confined and the injecting-cock shut, the engine remains in this position until the steam becomes strong enough by its pressure again to raise the *buoy* in the pipe, and a new stroke is begun; but if the steam be strong enough, as it most usually happens, then as soon as the piston has come to its proper height a new stroke is made, and the engine is almost in continual motion, and makes from twelve to sixteen, and sometimes twenty, strokes in a minute, whilst the outer end of the great beam works a pump of 8, 9, or 12 inches in diameter, and seven or more feet in length; *r*, a balance (or lever) one end of which turns up a pin, the other end is fasten-

ed to the higher end of the inceptor, 7, lower end fastened to the lever, 11: these, as have been described, rise and fall altogether by means of the buoy; *s*, a cup receiving overplus of water from *w*, and conveying it into boiler; *t*, a pipe conveying the injection water into cistern, having an immerged valve at the lower end; *v*, a pipe conveying waste water from the piston when it rises to the top of cylinder; *w*, a valve through which the air is forced by the steam; *x*, a cock supplying piston with water from cistern.

Although out of their place in the order of time, the engravings marked NEWCOMEN, D, and F, will be described here to give a more connected view of the variations introduced into the mechanism. That marked D, may be considered as the most perfect form to which it reached in common cases—E, a simplification of the entire system of opening the cocks, but which may be considered an attempt to show what might be done, rather than any view of machine that had been constructed. In figure D, *a*, is the steam-cylinder; *b*, piston; *c*, piston-rod attached to working-beam; *d*, cold-water pipe; *e*, injection-cock; *f*, sniffing-valve; *g*, a pipe conveying the water which falls upon the piston, into the reservoir; *h*, a pipe by which the boiler is supplied by the water heated within the cylinder; *i*, a branch of the same pipe carried into the reservoir, having a valve opening upwards at its lower extremity; *k*, the steam-pipe; *l*, sliding-valve; *m*, its axis, rising through the roof of the boiler, and attached to the lever of the horizontal fork, *n*; *o*, axis, of fork and tumbling-bob; *p*, *q*, prongs of tumbling-bob; *r*, *s*, *t*, spanners; *u*, plug-frame; *w*, tappet. There is a contrivance for moving lever of injection-cock similar to that for opening steam-valve; *x*, may be de-

scribed as its fork; *y*, its tumbling-bob; and *z*, its spanner. The operation of these parts will be readily understood by referring to the descriptions of the preceding figures.

In figure, E, *a*, is the cylinder; *b*, piston; *c*, piston-rod; *d*, cold water-pipe; *e*, injection-cock; *f*, sniffing-valve; *g*, a pipe conveying water from cup of cylinder to the cistern; *h*, a pipe conveying water to boiler; *k*, steam-pipe; *l*, valve; *n*, horizontal lever, which opens and shuts steam-valve attached at *m*, to a spanner, *o*, having a weight; *p*, which acts as a tumbling-bob; *s*, spanner of injection-cock, moved upwards and downwards by the rise and fall of the plug-frame, *t*, *u*, gauge-pipes; *w*, eduction-pipe, for the hot water formed by the condensation of the vapour.

The action of both of these engines will be understood from inspection, and they are here given in detail, more from a wish to exhibit all the early known steps of the engine, than from any importance which can be attached to them as parts of a mechanism which might probably offer useful hints to an inventor. In practice, the apparatus of Newcomen, even in this stage, absorbed in friction, and by the imperfection of the condensing process, nearly half of the entire power of the engine, not more than eight pounds being raised by each superficial inch of the piston; on a small scale, its effect was inferior even to that of the high-pressure engine of Savery. "Of this," says, Desaguliers, "I had an experimental proof at Westminster, in the year 1728 or 1729, when Mr. Jones (commonly called Gun Jones) built a working model of the lever engine in my garden, (which model he had a mind to present to the king of Spain.) I had at the same time near the place

where he erected his one in Savery's way, which raised ten tons an hour about 38 feet high.

"He made his boiler the exact size of mine, and his cylinder was six inches bore and about two feet in length. When his model or lever engine was finished, it raised but four tons per hour into the same cistern as mine. It cost him 300*l.*; and mine, having all copper pipes, had cost me but 80*l.**"

* P. 490, vol. ii. Experimental Philosophy.

CHAPTER SEVENTH.

"OFTENTIMES HATH IT BEFALLEN THE MOST EXPERT TO FIND THE SOUGHT-FOR LIGHTE IN A NOOK, FROM WHICH, IN HIS CONCEITE, HE DID HINDER THE FALLING THEREON OF THE FLINTE SPARKES."—*Vaughan.*

LEUPOLD, a native of Planitz, near Zwickau, at a very early age displayed so great a taste in designing machines, that his parents, unwilling to thwart a ruling inclination so strongly marked, placed him with a cabinet-maker and turner in his native village. But his constitution being found too delicate for enabling him to follow a mechanical trade with advantage, the youth, by their entreaties, was induced to sacrifice his taste to their anxiety for his health, and begin a course of study to prepare him for entering the church. He attended lectures on theology at Jena, and at Wittenburg, amusing himself in his hours of leisure in the fabrication of philosophical instruments. His ingenuity and diligence being observed by one of the professors, procured him admission to the library of the university, which contained a good collection of books on mathematics and philosophy. Leupold's early predilection returned with redoubled force, when he un-

expectedly found such ample means placed in his power to gratify it, and henceforth these congenial studies became his sole occupation. He greatly improved Hauksbee's air-pump, and performed some original experiments with mirrors; but he is best known as the author of a magnificent collection of descriptions and drawings of machines, which he began to publish, 1723, and continued through successive years, until he extended it to several folio volumes. In this comprehensive work his industry and research has collected accounts and views of every machine of which either models or descriptions were accessible. Yet this herculean task was not in his hands one of mere compilation; numerous improvements on many of the machines may be traced to their ingenious illustrator, and not a few of his own inventions enrich his excellent volumes. He suggests an ingenious simplification of the fire-wheel of Amontons, by giving a different form to the pipes and water-chambers. In the engraving, marked (LEUPOLD, 11.) *a*, *b*, *c*, *d*, *e*, *f*, are the outer or air-chambers; A, B, C, D, E, F, G, &c., are the water-chambers; and 1. 2. 3. 4. 5. 6. 7. 8. 9. pipes, forming a communication between the series of air and water-chambers, and *z*, *y*, *x*, *w*, *v*, *u*, pipes connecting the water-chambers placed on the opposite part of the circumference. N. fire-place; O. chimney; M. cistern of cold water. The action is the same as in Amontons wheel; the outer chamber, *a*, has its surface placed over the furnace, the air which it contains expanding, presses through the pipe, 1, upon the surface of the water in, *a*, and forces the fluid up the pipe, *z*, into the chamber, *g*, this gives that side of the wheel a preponderance, and the other chambers being brought in succession over the fire continuing this preponderance, a rotary motion is produced;

the air which has been expanded by being brought over the fire at one part of the revolution of the wheel, is condensed in its turn by the chamber which contained it being immersed in a cistern of cold water, in another part of its revolution.*

In Savery's engine, the steam, after it had forced by its elasticity the water to the required height, was condensed previous to the receivers being re-filled with cold water. Leupold, on the contrary, allowed the vapour to escape into the atmosphere after it had performed this office. In the engraving, marked (LEUPOLD, 111.) the steam proceeds from the boiler, *a*, through the pipe, *b*, and pressing upon the water in the receiver, *c*, forces it up the pipe, *d*, into the cistern, *e*, whence it is allowed to fall on the float-boards of a water-wheel to produce a rotary movement.†

When the vapour has expelled the whole of the water from the receiver, *c*, the cock, *f*, is turned, which opens a communication between the receiver, *c*, and the atmosphere, and between the opposite receiver, *g*, and the boiler: the vapour now forces the water from that vessel up the pipe, *d*, into the cistern, whence it falls on a wheel as before. During this operation, the escape of the steam from the receiver, *c*, allows the water in the reservoir to flow into it by the pipe, *n*; so that by the time the steam can be again turned from the receiver, *g*, into this vessel, it is filled with the water which is to be elevated into the reservoir; and so on, alternately.

In describing another machine, Leupold presents himself more in the character of an original inventor, than of an industrious commentator; and if his contrivance opens but a small field for an

* P. 403, vol. III. *Theatrum Machinarum.*

† P. 402, vol. III.—*Ibid.*

ambitious display of auxiliary mechanical detail, from his great experience in general mechanism, he saw, that this extreme simplicity was one of the best properties which could be possessed by machines constructed on any principle, and that this would, in fact, form one of its strongest and best claims to the introduction of this invention into general practice.* Neither did it escape his penetration, that the powers of this apparatus, under certain conditions, could be increased or diminished at pleasure, without demanding a corresponding enlargement or diminution of the cylinder, and that this variation in its energy might be produced without inconvenience, and with a rapidity which could leave nothing further to be wished for. Besides, the entire apparatus was not only simpler in form than Newcomen's, its parts fewer, but no greater delicacy of workmanship was required in their construction.

With the exception of Newcomen's invention, no motion had been produced by means of the intervention of a piston, which could be considered as at all adapted to practice. By Newcomen, as we have seen, steam was applied (instead of an air-pump) to make a *vacuum* under the piston, in order to permit its fall by the weight of the atmosphere; he was careful that the elastic force of the steam should never be called into action, it exerted, therefore, no *direct* action on *any part* of the apparatus in contact with it.

In illustrating the principle of Papin's digester, Leupold was led, by a very obvious step, to view what was considered to be its greatest defect, as opening a source whence might be obtained not

* P. 403, vol. III. *Theatrum Machinarum.*

only a more powerful but a more portable mechanical agent than had yet been moulded from the elasticity of steam. A piston raised by *vapour of a high temperature* might be placed at the end of a lever loaded with any weight, and instead of condensing the vapour which performed this office, it might be allowed to escape (as in his second scheme) into the atmosphere; and where a continuity of effect, as in pumping water, was desirable, two cylinders might be connected, so that when the steam from the one was escaping into the air, and, of course, producing no effect, in the other it should be forcing water into the reservoir: this, not differing greatly in a general view from his scheme already described, may be considered as the first successful attempt at the combination of, what has been called the *high-pressure lever engine.*

The view given of this contrivance by its inventor* is shown in the engraving (marked LEUPOLD.) The two steam recipients, or cylinders, each have a piston, *a*, *b*, fitted into them, and which are attached to a lever vibrating on its fulcrum, having a pump-rod fixed to the other end. A communication is opened with the boiler by means of a channel, *d*, and the under side of the piston, *a*, and the expansion of the vapour raises it to the top of the cylinder; this presses the pump-rod (placed at the other end of the lever) downwards in the pump-barrel, and the plunger or piston being solid, the water beneath it is pressed to the required height up the pipe, *i*. When this piston has been raised to the top of the cylinder, the *fourway-cock* is turned round, and the channel, *d*, opens a passage for the steam to flow from under the

* P. 403, vol. III. *Theatrum Machinarum.*

piston, *a*, into the atmosphere; and, at the same time, the channel, *e*, is brought into a position similar to that which *d* had occupied, and thus allows steam from the boiler to enter under the piston, *d*, this is now elevated in its turn; *c*, is the boiler; *h*, the furnace.*

In the two last figures, the return of the water which has been raised is prevented by the usual means of a puppet-clack, or valve, opening upwards.

The candid and disinterested Leupold confesses that he owes the idea of the fourway-cock,† and the use of very elastic steam to raise a piston, to a perusal of the writings of the ingenious Doctor Papin, and ascribes to him all the merit of his combination. But, without wishing to detract the smallest portion of praise from the labours of that most ingenious, but neglected philosopher, it were injustice to deny Leupold the praise of erecting a valuable superstructure on a foundation, which, in truth, should be said to have been indicated rather than laid by the industrious Papin.‡

The operation of the fourway-cock will be easily understood from the figures. The channels from the cylinders and from the boiler are fixed, and those in the moveable cylinder are perforated in a curved direction, so that they may be turned either to continue a communication between the recipient

* See p. 90.

† The valve below the plungers in the engraving should have been shown reversed in position.

‡ A similar idea occurred to Mr. Watt.—"I intend in many cases to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner as the pressure of the atmosphere is employed in common fire-engines. In cases where cold water cannot be had in plenty, the engines may be wrought by the force of steam only, by discharging the steam into the open air after it had done its office."—*Specification of Patent*, 1769.

and the boiler, or between the cylinder and the atmosphere. Leupold took it from Papin's air-engine, but, as usual in his hands, it received considerable improvement.

Some insulated attempts at minor improvements may here be noticed. Beighton formed a table of calculations, in 1721,* for the proportions of some of the details; but, in other cases, a repetition of what had been long done in one country, was published as an improvement by a native of another. Mey and Meyer's apparatus,† of which an excellent engraving and detailed description were given by the French Academy of Sciences in 1726, was then in action at Passy, near Paris. It is similar to that which has been described by Desaguliers. Bosfrand shortly afterwards presented to the same society, drawings and a description of an engine, containing what he considered improvements wanting to be made on Mey and Meyer's. One of the most notable of these, was a valve inserted into the side of the cylinder, and near to its top, which was closed by a weight, hung from the end of a steel-yard—this was a contrivance to allow the steam to escape when it was "too strong in the cylinder!"—his sniffing-clack was placed at the bottom as usual. About equal in merit to that which has now been detailed, are some other minor additions found in this, and not in the engines in common use. The whole description gives a good idea of the ignorance of the first principles of the machine; which, at this time, prevailed even among persons generally accounted intelligent and well-informed.

Bosfrand's other engine,‡ of which, also, a good

* P. 316, *Ladies' Diary*, 1721.
† P. 209, tom. IV. *Machines Approuvées*.
‡ P. 214, vol. IV, *Machines Approuvées*.

engraving is given in the same volume, is similar to that which has been described, as claimed by Desaguliers—and made by him for the Czar Peter, nearly ten years before—with the alteration of—forming the two gauge-pipes, to be opened and shut by one cock, on the construction of the four-way cock of Papin.

CHAPTER EIGHTH.

"IN PROPORTION AS EXCELLENT PRODUCTIONS SHALL MULTIPLY, EVERY SUCCESSIVE GENERATION OF MEN WILL DIRECT ITS ATTENTION TO THOSE WHICH ARE MOST PERFECT, AND THE REST WILL INSENSIBLY FALL INTO OBLIVION. BUT THE MORE SIMPLE AND PALPABLE TRAITS WHICH WERE SEIZED BY THOSE WHO FIRST ENTERED THE FIELD OF INVENTION, WILL NOT THE LESS EXIST FOR POSTERITY, THOUGH FOUND ONLY IN THE LATEST PRODUCTION."—*Condorcet.*

The knowledge of the construction and peculiarities of steam-machinery, extending by degrees among classes less directly interested in it, as a subject for mechanical practice, than for the purpose of philosophical illustration, had given rise to an opinion, that its invention sprung from scientific deduction. But Desaguliers ridicules this notion of its origin: "if," says he, "it is imagined, that it must be owing to great sagacity, and a thorough knowledge of philosophy, that such proper remedies for the inconveniences and difficult cases were thought of, here has been no such thing, almost every improvement has been owing to chance." And it was probably waiting for similar good fortune, that many parts of the machinery were left by later mechanics to chance for their further improvement.

Great care and no small ingenuity had been expended on the cylinder and its appendages; the boiler had received a portion of attention, and its

shape was regulated by geometrical canons, and the furnace, too, was not quite forgotten, for the smoke flue was made to meander, in every possible way, round the boiler; and it may have been that its meanderings were advantageous. But the circumstances which mainly effected the general loss of power not being agreed upon, opened a field of contention, which was at all times fully occupied. "The attendant," said one improver, "is careless, and he does not feed the fire so copiously as he should. A large furnace—ample surface of grate-bar and plenty of coal, what more is necessary?—if a failure of effect is still apparent, let the coal-binn be examined, and judgment given to bury the lazy or niggardly engine-man under his miscalled savings. My furnace will consume any thing, and raise steam in an hour sufficient for a day." "But it will do better," says a second, "if my boiler is placed over it." "Without my piston and steam valve," says a third, "in my opinion, your schemes will prove abortive." And thus rival mechanists carried on a petty warfare, each depreciating his neighbour's nostrum, and earnestly recommending his own. There was however one fact acknowledged by all—enormous quantities of coals were engulphed in the furnace.

It was a boast with those who were interested in the erection of this kind of machinery, that the great expenses incurred for draining coal mines were absolutely saved altogether by using the fire-engine—for it may be worked, they said, with the refuse of the produce of the mine—which is not only unsaleable, but whose accumulation on the surface is a positive nuisance.

Whatever shadowings of truth gave relief to this statement, experience quickly taught, that in the most favourable cases, the economical advan-

tage was bounded within narrow limits;—and the furnace of a fire-engine, even at the *mouth* of a coal mine was like other monsters, whose voracity, although it might partly be satisfied by devouring garbage, required to be often stimulated by substances of more value;—and the "good coal, the market article," that was thrown in, to propitiate, as it were, "the refuse" to do its office, became a serious item of deduction from the gross profit:—where the whole supply was to be brought from a distance, and bought at a high price, the consumption of fuel was beheld with astonishment, and the worldly-minded proprietor, on reckoning up its value, was struck with dismay.

The first attempt to form an estimate of the quantity of fuel, that ought not to have been thrown into the "burning fiery furnace," by observing how much made its exit in the primitive state at the chimney-top, was made by a Doctor John Allen, in a book,* which he published in 1730. He found, that "in the common method of boiling water (since the invention of setting boilers in furnaces) by the application of fire under the bottom, and round the sides of the boilers, notwithstanding how much soever it may exceed the boiling of water in a kettle over an open fire, it is *evident*, that well-nigh half of the heat or effect of the fire is employed in heating the walls of the fire-place; and in the best contrived furnaces that he ever saw, the current of flame and heat, after having fetched one single compass by a flue round the boiler, made its exit presently into the tunnel, whence it escaped into the air, and further benefit and advantage was entirely lost."

In his experiments to provide a remedy for this

* *Specimina Ichnographia, or a brief narrative of several new inventions.* London, 1730.

expensive evil, he ascertained, that water evaporates after the rate of an inch and a half in depth per hour; from which he drew the conclusion, that the larger the surface of boiler exposed to the action of the flame, the greater would be the evaporation or production of steam. He, therefore, placed his fire in the centre of the boiler, and by this means it was surrounded by the water which was to be heated.—His furnace was of copper, brass, or iron, of a peculiar form or feature, (similar to that used in modern steam-boats,) and the water was contained in the space round it by a vessel of wood, lead, or any other material that would hold water.*—This was his first scheme. The second is similar, with this difference only, that, as he had observed, in common cases, the flame rise above the chimney-top, after encircling the boiler once, he made his smoke-flue with numerous cork-screw-like *windings* through the water, in the manner of the worm of a still; lest the length of the passage should extract *all* the heat from the smoke, and thus act as a

* "The mode of conveying flame through water had been practised by others before my time, (1770,) and was common in the Cornish mines. The inventor is unknown, but a person of the name of Swaine was a great propagator of the practice.—Watt, in Robison's *Mechanical Philosophy*, vol. ii. This was probably Allen's mode; but it was also known before his time. Sir Robert Moray and Dr. Goddard, in 1663, proposed brewing beer in a kettle, having only a brass bottom; and in the middle thereof, a globe of brass open at the lower end, into which the fire goes, whereby the brass of the rest of the kettle is saved. Glauber used *wooden casks* for boilers, but he boiled the water they contained by a small copper globe, (a pipe from which was inserted into them,) placed in a furnace heated with sea-coal,"—"a contrivance," says Hooke, when describing it, "which, if prosecuted, might be perhaps very beneficial to brewers, dyers, and such other trades as have occasion to make use of great quantities of water heated."

"damper" on the fire-place; he recommended the employment of a large pair of bellows for forcing the sluggish vapour into activity.

Meritorious as these schemes must be thought, considering the period at which they were proposed, it does not appear that much benefit could arise from their adoption, with the exception of the saving of the heat which was absorbed by the fire-place; and probably, also, of that portion which was lost by radiation from the surface of the boiler when formed, as was usual, with copper or iron—for the wooden boiler could not radiate much. The doctor made no attempt to ignite the gaseous product of the coal before it passed into the "tunnel." This was left to find its way as before, merely "cooled a little," into the atmosphere.

The explanation of these schemes, and a discussion of their advantages, occupy the first chapter of the Doctor's treatise. The second is devoted to an account of an invention of a more imposing character—a mode of navagating a ship in a calm.

Other projects for propelling a ship in a more expeditious and less laborious way than by oars, which had been proposed by others, he enumerates, before entering upon the merits of his own. "In these," he says, "the motion was communicated by machinery, working *without* the ship, something analogous to oars or paddles, or by the revolution of wheels turned by a capstan placed within the ship." No part of his machinery, on the contrary, was placed on the outside of the vessel.*

* He quotes an experiment made by a French author on the gallies in the Mediterranean. "A fifty-two-oared galley, the oars thirty-six feet long, with three men to each, moves

The way he proposed to get a power and avoid the defect, which attached to every method that had been practised or proposed, was to form a tunnel or pipe open at the stern or hinder part of the vessel; and by means of a pump to force water or air into it through the sea, and by the reaction which this would occasion, the ship would be driven forward, very accurately "imitating what the author of nature has shown us in the swimming of fishes, who proceed in their progressive motion, not by any vibration of their fins as oars, but by protrusion with their tails; and water-fowls swim forward by paddling with their feet behind their bodies."*

The doctor carried his scheme into practice, in a boat of considerable size upon a canal; and from that and other experiments, he felt certain, that the protrusion of *something* at the stern was the true way to navigate a vessel.—But his scheme is detailed here, on account of his suggestion, that the operation of pumping, which was performed by men in his trials, could be better accomplished by the power of a steam-engine, "and he could have no manner of doubt that, if a couple of them were applied to a ship of four-

at the rate of three miles and three-quarters an hour.—This effect is equal to a force of fourteen pounds exerted by each rower; the cross section was equal to eighty square feet."

* "It may be remarked, that, at a very early period, aquatic automata, furnished with wheels and other similar contrivances, were moved by other means besides those derived from animal power. *Roger Bacon*, de Admirabili Potentia artis et naturæ—and J. C. Scaliger, *exercit.* 326, ad Cardanum.—Babington's *Pyrotechnia*, cap. 60.

"In 1732, The Comte de Saxe revived the project of wheel-boats, and presented an account and plan to the Academy of Sciences, of a barge moved by a wheel placed on each side of the boat." Tom. vi. p. 41, *Machines Approuvées*.

teen or fifteen hundred tons, they would impel it at the rate of three knots an hour."*

Gensanne describes his engine as combining the improvements which made Newcomen's a self-acting machine, with a greater simplicity of parts than had been used when constructing an apparatus on Savery's principle: *a*, is a receiver; *b*, pipe from cistern; *d*, injection-pipe and cock; *e*, *f*, the lever of the steam or regulating valve; *s*, *g*, the fork which moves it backwards and forwards; *h*, *k*, parallel levers; *i*, lever moving on an axis; *o*, attached to parallel rods; *m*, *n*, tumbling-bobs; *r*, *s*, boxes attached to each end of lever *i*, each having a valve opening upwards to allow the water with which they are filled to escape. The rise and fall of a tappet or slider-pin fixed in the rod, *h*, which is inserted in the slider, forming the continuation of the lever or axis of injection-cock; *x*, boiler. In the engraving the parts are shown in the position of the injection-cock, being open, and the steam-cock shut, and the receiver filled with water. At this instant the mechanism is so arranged that the water-box, *s*, is empty, and the opposite one, *r*, is filled to its limit with water: the end of the lever on which it is fixed preponderates, and it moves downwards, (the valve in the bottom of the cistern from which it was filled, closes of itself by the weight of water on it.) The slider of the injection-cock is also moved downwards, which closes it; and during the same moment, the fork reverses the position of the steam-valve, and opens it; approaching nearly to the limit of its stroke, the lever comes in contact with the arm of the tumbling-bob, *n*, and raising its weight beyond the

* P. 14, *Specimina Ichnographica.*

perpendicular, receives a sharp impulse from its quick fall; this completes the operation. At this instant a spindle of the valve in the bottom of the box, *r*, is thrust upward, and the water which it contained escapes through it;—and at the same moment the box, *s*, which had been elevated by the rise of the other end of the lever, thrusts the spindle of the valve, placed in the bottom of the cistern also upward; and receives the water which falls from it. When it is filled, the preponderance which is given to the end of the lever on which it is fixed carries it downwards. This reverses the position of all the other parts,* and it is obvious the movement may be repeated.

Another mode of applying the power of a steam-engine to navigate a vessel, was suggested by Jonathan Hulls in 1737.† But the scheme, although a nearer approach to the present form of the steam-boat than Allen's, can neither be considered as the first suggestiou for moving wheels by steam, nor any improvement on the idea which emanated from another ‡—nor even any specimen of mechanical skill, for it is awkward, clumsy, and inartificial; but, as his claims have been put forth to a higher place than is here assigned him, they will be better understood by a reference to the engraving marked HULLS, 1737, and the description of it which follows nearly in his own words. It is doubtful whether Hulls ever proceeded beyond printing a description of his project.

* P. 222, vol. vii. *Machines Approuvées.*

† *A description and draught* of a new-invented machine for carrying vessels or ships out of or into any harbour, port, or river, against wind or tide; or in a calm. Lond. 1737. It is a pamphlet, by no means scarce, containing forty-eight pages, about eight of which have any reference to his invention. Hulls took out a patent.

‡ See page 97.

"*a*, chimney coming from the furnace; *b*, tow-boat; *c*, *c*, two pieces of timber framed together to carry the machine, *d*; *x*, *y*, *z*, three wheels on one axis to receive ropes, *s*, *t*, *u*; *t*, being rope that goes into cylinder; *m*, *n*, two wheels on same axis with the fans, *i*, *i*, *i*; *u*, is a rope going from wheel, *n*, to *z*; that when the wheels, *x*, *y*, *z*, move forward, moves wheel, *n*, forward, and the fans along with it; *s*, a rope going from wheel, *m*, to the wheel, *x*, so that when the wheels, *x*, *y*, *z*, move forward, the wheel, *m*, draws the rope, *s*, and raises the weight, *g*, at the same time as the wheel, *n*, brings the fans forward.

"When the weight, *g*, is so raised, while the wheels, *x*, *y*, *z*, are moving backward, the rope, *s*, gives way, and the power of the weight, *g*, brings the wheel, *m*, forward, and the fans with it, so that the fans always keep going forward, notwithstanding the wheels, *x*, *y*, *z*, move backwards and forwards as the piston moves up and down in the cylinder: *o*, *e*, teeth for a catch to drop in from the axis, and are so contrived, that they catch in an alternate manner, to cause the fans to move always forward; for the wheel, *m*, by the power of the weight, *g*, is performing its office while the other wheel, *n*, goes back, in order to fetch another stroke. The weight, *g*, must contain but half the weight of the pillar of air pressing on the piston, because the weight is raised at the same time as the wheel, *n*, performs its office; so that it is, in effect, two machines acting alternately by the weight of one pillar, of such a diameter, as the diameter of the cylinder is." Hulls, aware that objections might be urged against its want of originality, endeavours to anticipate them; "if it should be said," says he, "that this is not a new invention, because I make use of the same power

to drive my machine, that others have made use of to drive theirs for other purposes, I answer, The application of this power is no more than the application of any common and known instrument used in mechanism for new invented purposes."

It may, however, be observed, that he considers that it would not be practicable to place his apparatus on board of the ship which it is required should be moved—but that a separate vessel should be appropriated to its reception, and that this should be used as a tow-vessel; and he urges several economical reasons in favour of his *Tow-Boat*. The manner of converting the rectilineal motion of his piston into a rotary one, is very ingenious.*

Payne, in his narrative of a "new method of expanding fluids, by their being conveyed into certain ignified vessels, where they are immediately rarefied into an elastic impelling force,"† exhibits considerable originality of idea as well as construction. His boiler, which he called his expanding vessel, was shaped like a balloon, the greater end of which formed the roof; a pipe was carried through the top of this expanding vessel, which had a kind of horizontal drum fixed upon it. On the periphery of the drum or *disperser* were placed a radiating series of small pipes. The lower end of the vertical pipe, which may be called the axis of the disperser, was formed as a pivot; this turned in a socket, supported by a bracket. The upper end of the pipe (outside of the balloon) was fitted with a cog-wheel, which

* About this period three fire-engines were in operation in France, one at Fresne, near Condé; one at a coal mine at Sars, near Charleroi; a third at a lead mine near Namur.—Gensanne, p. 300, vol. vii., *Machines Approuvées*.

† P. 821, vol. XLI. *Philosophical Transactions*.

worked into another. The flue of the furnace encompassed the *middle* division of the balloon. When water was introduced into the upper end of the vertical revolving-pipe it fell into the drum, and by its revolution was thrown through the small radiating pipes on that portion of the balloon exposed to the action of the furnace, and a rapid production of steam was thus occasioned. The water which was not converted into vapour fell to the bottom or narrow end of the balloon, and was conveyed away by pipes, placed there for that purpose. Payne says, he evaporated forty gallons of water in an hour, which supplied a twenty-four inch cylinder by this method; and in experiments made at Wedgebury and Newcastle he rarefied ninety gallons of water in an hour, by one hundred and twelve pounds of pit-coal, being, he says, about one-third only of the fuel required to do the same thing in common boilers. He stated the expansion of steam at four thousand times the bulk of water which formed it—a better guess than any that had yet been offered.

It is uncertain whether he succeeded in introducing his clever plan into practice—probably not, for ten years afterwards, Blake, in a paper read before the Royal Society in favour of wide and short rather than narrow and long steam cylinders, notices "that the prodigious vessel of water to be kept boiling, when only an inconsiderable part of it is employed in the work, savours too little of the frugality of nature, which we ought ever to imitate."*

In the same year Smeaton gave an account of a self-acting engine on Savery's principle, invented

* *Philosophical Transactions*, p. 200, vol. XLVII.

by a Portuguese gentleman. A light ball of copper formed a float within the receiver; this was attached to an axis or spindle, passing through a socket to the outside of the vessel. The float rises and falls, with the rise and fall of the water, and communicates a corresponding motion, to a series of levers or gears on the outside, adjusted to make the motions simultaneous.* By this Mr. de Moura performed the same thing, by means slightly different from those employed by Gensanne some years before.

The project which had several times been discussed by the Academy of Sciences, when individuals presented to their notice schemes for moving vessels by other aids than wind or oars, was in 1757 propounded as the subject of their prize essay. The celebrated Daniel Bernouilli demonstrated the effect of several mechanical combinations, which might advantageously supply the power derived from wind or oars. He gave the preference to paddle-wheels, which he † suggested might be moved by steam or gunpowder. Gautier, a canon of Nancy, did not, in his essay,‡ exhibit such unbounded power over the medium by which his ideas were illustrated, as was possessed by the mathematical giant who bore away the prize in this competition; but in the details of his scheme he shows a finer mechanical tact than his rival Bernouilli. A steam-engine, with several ingenious modifications to produce rotary motion, is made to turn paddle-wheels placed at each side of the boat, as recommended by Duquet in 1693. His essay throughout shows him to have been

* P. 437, vol. XLVII, *Philosophical Transactions.*

† P. 94, tom. VII, *Recueil des Pièces qui ont remporté les prix,*

‡ P. 251, tom. III, *Mémoires de la Société Royale de Nancy.*

rich in mechanical resources, and we remark with surprise such clear and distinct notions, on a perfectly novel and difficult subject familiar to a man who had always lived in an inland town, and totally ignorant of maritime affairs.

It was a favorite project of Dr. Hale's to increase the evaporation from sea-water during the process of making salt, by artificial ventilation.* Kean Fitzgerald, in 1757, applied the Doctor's idea to the production of vapour to supply a fire-engine He inserted one end of a pipe into the water of the boiler, and to the other end he fitted a huge pair of bellows, his project being to blow *air* through the hot water, which would rise as steam into the cylinder. Putting the bellows in action, he produced as he had anticipated, about a sixth more vapour than was generated when blowing was not resorted to. Here the increase, although considerable, not being quite equal to his expectations, he proceeded to a second trial, in the hope of making a greater impression; a new pair of bellows was constructed for the occasion, larger, stronger, and tighter than those used in the first experiment, but on attempting to blow into the boiler, the bellows stood as stiff as if they had been solid within: they were loaded with a weight of several hundred pounds, but still they resisted compression as before. The cause now became obvious, a force must be applied to empty them greater than that which was opposed by the elasticity of the steam in the boiler; but as the top of the bellows had a surface of nine or ten square feet, to place ten or eleven pounds on each square inch of this area, was beyond his ability.

* P. 128, vol. L, *Philosophical Transactions.*

When the steam-cock was opened, a little air, it was found, might be injected. The most extraordinary circumstance of all was, that although the experimenters were quite satisfied that not a particle of air entered the boiler, there was an increase of steam during the second experiment, equal to that during the first.

The first and second experiment coincided perfectly together when the "results were compared," and a careful inspection of the "old bellows," showed further that the two trials coincided in every thing. In fact, the air which was supposed to have passed through the hot water, in the first attempt, and was considered, after having assisted in filling up the cylinder, to have passed into the atmosphere through the "sniffing clack," took a much shorter path, and glided quietly through a crack which had not been observed in the bottom of the "ventilating bellows."

Fitzgerald, a good-natured man, disarmed the ridicule which his experiments' might have provoked by explaining the cause of his failure as candidly as he had stated the value of his invention; and he consoled himself and the society by an assurance that, mistaken as he was, and misled, as they had been as to the cause of the increase of steam, that increase in reality was produced; for by the constant *care* that was taken during the time of making these experiments "to measure the coal, and to admit only a proper quantity to be laid on, and also to mark the time it took exactly in burning, the engine then required eight bushels of coals less in every twenty-four hours' work than it did before; and also from the regularity of its stroke it threw up more water; the same care being required from the engineer, afterwards he

had no pretence for consuming more coals than appeared sufficient during the time the experiments were making."*

Fitzgerald's next attempt at improvement was less equivocal, and his method of converting the reciprocating motion of the piston rod of an atmospheric engine into a rotary one, was not wanting in ingenuity. "He employed a combination of larger toothed wheels, and of smaller ratchet wheels, worked by teeth upon the arch or sector of the great beam; one of these ratchet wheels being put in motion by the ascent of the beam, and standing still during its descent, when another ratchet wheel is moved by an intervening wheel in the same direction as the first; and thus the two communicated a continuous rotative motion to the axis on which they are placed, which is thence transmitted by a larger toothed wheel to a smaller wheel or pinion, on the shaft of which is *a fly* to communicate a momentum, and a crank proposed to be applied to work ventilators, and to many other useful purposes. The fly, by accumulating in itself the power of the machine during the time it was acted upon, would continue in motion, and urge forward the machinery, whilst the steam-engine was going through its inactive returning stroke." Fitzgerald is said to have had a patent for this invention, but Mr. Watt, after a search, could not succeed in finding that he had. "He published proposals for erecting mills of all kinds driven by steam-engines, but his proposals did not meet with the confidence of the public."†

Brindley's scheme (1759) of reducing the expense of fuel in steam-engines, by a novel construction of the boiler, resembles Doctor Allen's,—he formed

* P. 373, vol. I., *Philosophical Transactions.*
† P. 118, vol. II. *Robison's Mechanical Philosophy.*

the top and sides of his boiler of wood, and the bottom of stone; the fire-place was placed within, and surrounded with water. The rapid decomposition of the wood was, however, found to be an objection to its use in practice.

About this time a notice of the use of the atmospheric engine in America first occurs, and a little later two were stated to be in operation at a copper-mine on the Passaick. All the engines in operation, either on the continent or in America, were constructed by English mechanics.

The improvements of the mechanism stimulated many projects for adapting its agency to other purposes, besides that of raising water, and the scheme of John Theophilus Cugnot, a native of Void, in Lorraine, is meritorious from its novelty and for its successful practical developement. In his youth Cugnot served in Germany as an engineer. Passing afterwards into the service of prince Charles of Lorraine, he resided at Brussels, and gave lessons in the military art, with the theory and practice of which he was profoundly acquainted. The invention of a light gun procured him the notice of the Comte de Saxe, to whom about 1763 he exhibited a model of a carriage moved by a steam-engine instead of horses. He afterwards lived at Paris, and through the recommendation of the Comte, obtained the patronage of the Duc de Choiseul, then minister at war. He was now (1769) enabled, at the public expense, to construct a large carriage, the wheels of which were moved by a steam-engine, similar to that of the model of 1763. At the first trials (1770) of this novel vehicle, before a numerous assemblage of official and professional persons, its movements were so violent as to overturn a portion of wall which was opposed to its progress. This unfortunately

produced an opinion, that, in consequence of the uncertainty of obtaining proper mechanical control over its motion, it could be of small use in practice. The project was therefore abandoned, and the experimental machine was deposited in the museum of the Arsenal,* to become a point of reference to the epigrammatist, and a memorial of the blasted hopes of its accomplished author. Cugnot's genius expanded half a century too soon, either for its value being known, or its efforts cherished. At a later period of his life, his means of subsistence having fallen into decay, the various services he had rendered to the public were thought to entitle him to a reward from the state. The revolution sweeping away even this pitiful pension of twenty-one pounds a year, Cugnot must have perished of hunger but for the compassionate benevolence of a lady of Brussels. With the kindness natural to woman, she not only provided for the wants but watched with tenderness over the personal comforts of the now feeble and helpless old man, until the well-known Mercier succeeded in drawing the attention of Napoleon Bonaparte to the miserable fate of his ancient and aged friend. Cugnot died at Paris in 1805, in his 80th year, in a state, to him, of comparative affluence,—the enjoyment of an annuity from Napoleon, about double in value to that of which he was deprived by the overthrow of the monarchy.

It would be difficult to value the claims urged by Blakey, as author of an improvement on Savery's machine, from his own account of its properties and advantages. He appealed to an experiment,† and by its result, his claim may be fairly

* It is now placed in the *Conservatoire des Arts et Métiers.*

† "Great contention arose among some of those who counted

decided. His idea was to make a quantity of *oil* or *air* float on the surface of the water in his receiver, and by this means to prevent the great condensation that took place when the vapour, in the common engines, came into contact with the surface of the water in the receivers. The oil and the air he considered would act as a piston, having a very small conducting power: *a*, the boiler; *b*, pipe conducting steam from it into the cylinder, *c*, injection pipe, perforated with small holes passing through the cylinder into the steam pipe; *d*, pipe connecting the upper cylinder with a similar one, *e*, placed beneath it; *g*, a pipe opening into the atmosphere, and opened and shut by means of a ball-cock; *h*, a pipe for occasionally emptying the cylinder; *i*, *k*, valves permitting the rise of water in the pipes, *l*, *m*, but preventing its return; *n*, eduction pipe; *o*, pipes from cistern; *r*, a cullender with small holes to disperse the injection-water equally.

The injection cock is to be shut and the steam cock opened, and the flow of steam from the boiler will speedily fill the apparatus, expelling the air which it contained through the pipe used for occasionally emptying the cylinder; when the air is expelled, the steam cock is to be shut, and the injection cock opened; a vacuum is thus produced

themselves men of science, as to the practicability of such a project, some giving it as their opinion that, if the principle were to be admitted it would be very difficult to apply it in mines, where it would require ten atmospheres at least, while others, with exalted pretensions, declared it possible to conduct its influence to the centre of the earth. But an accident terminated the event, as to this engine, in Cornwall, by one of the steam vessels bursting, through the force of the steam; though much under the degree of power proposed to the Cornish gentlemen."—p. 306., vol. ii. *Gregory's Mechanics.*—1st edition.

in both cylinders. Water from the cistern is forced up the pipe, *o*, into the lower cylinder, and rising upwards moves the floating ball attached to the cock or the pipe, *g*; this opens it, and permitting the air to fill the upper receiver, the farther rise of the water is prevented—the steam cock is now opened and the injection cock shut, and the vapour presses the air from the upper cylinder into the lower, and this in its turn forces the water beneath it through the pipe *x*, into the eduction pipe. The escape of the air through the pipe *g*, at the commencement of the operation, is prevented by the operation of a small valve placed at the end of the pipe which opens upwards. When the air has been expelled from the upper receiver, its decent has in its turn forced the water from the under vessel into the reservoir. The injection cock is then opened, and the vapour is condensed; the air in the lower vessel expands upwards, and forming a partial vacuum in both, permits the rise of the water from the cistern;—its ascent again lifts the ball cock and opens through the pipe, *g*, the communication with the atmosphere and upper cylinder which is again filled with air; the injection cock being shut, and the steam cock opened, the vapour forces the air before it, and that communicates its motion to the water, as has been described, and these alternations produce the effect intended. On trial the scheme failed, and Blakey was added to the list of unsuccessful speculators—not, however, without exerting the privilege of complaining of patronage being withheld, and promises broken.

The various views of the atmospheric engine which have been already given, may probably be considered more than sufficiently numerous for the illustration of a mechanism whose use is soon to

become obsolete; but justice to those who are to follow, as much as to those who have gone before, required ample notices of the various forms Newcomen's apparatus received, before it was superseded by another combination. The most perfect models will be found described at great length in the works of Smeaton.

"This eminent man was born an engineer; his playthings were not those of children, but the tools men work with, and he had always more pleasure in observing artificers work than in joining in juvenile amusements."* The elder Smeaton was an attorney, and the son, yielding to parental wishes, attended the courts at Westminster, to fit him for practising his father's profession. But his disgust of what he called "the sordid employment" overcame his strong filial resolution, and following the impulse of his genius, he began his brilliant career as an experimental philosopher, engineer, and mechanic.

* "Early in life, he attracted the notice of the duke and duchess of Queensberry, from a strong resemblance to their favourite Gay, the poet. The commencement of this acquaintance was singular, but the continuance of their esteem lasted through life. Their first meeting was at Ranelagh, where walking with Mrs. Smeaton, he observed an elderly lady and gentleman fix an evident and marked attention on him. After some turns, they at last stopped him, and the duchess, of eccentric memory, said, "Sir, I don't know who you are, or what you are, but so strongly do you resemble my poor dear Gay, we *must* be acquainted, you shall go home and sup with us; and if the minds of the two men accord as do the countenance, you will find two cheerful old folks, who can love you well, (and I think or you are an hypocrite,) you can as well deserve it." The invitation was accepted, and as long as the duke and duchess lived, the friendship was as cordial as uninterrupted; indeed, their society had so much of the play which genuine wit and goodness know how to combine, that it proved to be among the most agreeable relaxations of his life—a sort of amicable and pleasant hostility was renewed, whenever they met, of talent and good humour,

"It was a favourite maxim of his, that the abilities of the individual were a debt due to the common stock of public happiness or accommodation. This governed his actions through life; for the claim of society, (thus become sacred,) his time was devoted to the cultivation of talents by

in the course of which, he effected the abolition of that inconsiderate indiscriminate play amongst people of superior rank, or fortune, which compels every one to join, and at their own stake too; he detested cards, and, his attention never following the game, played like a boy. The game was Pope Joan, the general run of it was high, and the stake in the "pope" had accidentally accumulated to a sum *more* than serious—it was Smeaton's turn by the deal to double it, when regardless of his cards, he busily made minutes on a scrap of paper, and put it on the board. The duchess eagerly asked him, "what it was," and he coolly replied, "Your Grace will recollect the field in which my house stands, may be about five acres, three roods, and seven perches; which at thirty years' purchase, will just be my stake; and if your grace will *make a duke of me*, I presume the winner will not dislike my mortgage." The joke and lesson had alike their weight; they never after played but for the merest trifle."—p. 29. vol. I. *Reports* of the late John Smeaton.

"The submission of his temper, naturally warm, to reason and benevolence, is strongly illustrated by the following circumstance:—A man formerly employed by him as a clerk, and for whom, having the highest confidence and esteem, he procured a similar though more lucrative situation in a public office, where he served with a fidelity, which in time promoted him to a station of high trust and responsibility, and Smeaton became bound with another gentleman for his conduct in a considerable sum. It were needless to say by what degrees in error this man fell. At last, he forged a false statement to meet the deficiency—was detected and given up to justice—the same post brought news of the forfeiture of the bond; of the man's compunctions and danger; and of the refusal of the other surety to pay the moiety. Yet, although Smeaton disbursed the whole, amounting to some thousands, all that could soothe the remorse of a prisoner, every means which could save him, (which did at least from public execution) were exerted that could be prompted by the most active benevolence."—P. 28, vol. I. *ibid.*

which he might benefit mankind, and afterwards to the unwearied application of them. The arrangement of his time was governed by a method as invariable as inviolable; professional studies were never broken in upon by the calls of pleasure or indolence." By his unremitting industry, unyielding integrity, and habitual caution, he stood without a rival in his profession and was called upon for his advice and direction in the greater number of public works which, during his life, were undertaken in his own and other countries.

The steam-engine had a great share of his attention; and if there is nothing which can be pointed out as having been added by his invention, he is probably that individual to whom is due the greatest share of the merit of giving the most perfect form and proportion to those materials supplied by his predecessors and cotemporaries.

CHAPTER NINTH.

"THE INTRODUCTION OF NEW INVENTIONS SEEMETH TO BE THE VERY CHIEF OF ALL HUMAN ACTIONS. THE BENEFITS OF NEW INVENTIONS MAY EXTEND TO ALL MANKIND UNIVERSALLY, BUT THE GOOD OF POLITICAL ACHIEVEMENTS CAN RESPECT BUT SOME PARTICULAR CANTONS OF MEN; THESE LATTER DO NOT ENDURE ABOVE A FEW AGES, THE FORMER FOR EVER. INVENTIONS MAKE ALL MEN HAPPY WITHOUT EITHER INJURY OR DAMAGE TO ANY ONE SINGLE PERSON. FURTHERMORE NEW INVENTIONS ARE, AS IT WERE, NEW ERECTIONS AND IMITATIONS OF GOD'S OWN WORKS."—*Bacon.*

The river Clyde, rising in Annandale, in its course round the base of the hill of Tinto, flows through some of the finest meadow-lands in Scotland; and falling from its elevated level in magnificent linns, glides onward through a luxuriant valley, having its banks adorned with proud castles and palaces, cheerful cottages, prosperous villages and towns, and continuing throughout its lengthened course to enliven a succession of scenes, unrivalled for their pastoral and romantic beauty.

A hill that shelves gently to the north bank of this noble stream, at a spot where it becomes navigable to the ocean, was selected by Saint Kentigern for the site of a religious establishment. Here also the gratitude of David I. enabled his preceptor, Achaius, to found a stately cathedral, which still remains a venerable and majestic ornament of the "northern Corinth." In later times, by the munificence of Bishop Turnbull,

the rising town was distinguished by the erection of an university, which shedding the genial influence and polish of literary tastes over the coarser pursuits of commerce, a generous and liberal spirit of enterprise has been diffused through the wealthy mercantile community which sprung up, and has continued to gather and flourish around it.

At the period of our narrative, a youth might occasionally be observed during the hours allotted for his recreation, exhibiting a box of philosophical toys to the students assembled at the college gate. Of a slender form, and sickly in his appearance, his retiring and bashful manners but ill accorded with the assurance required to attract attention to a collection of "candle-bombs" which he had fabricated, and hoped by their sale to add to the means of his boyish enjoyments.

The youth James Watt,* had received the ele-

* His great grandfather cultivated his own small farm in the county of Aberdeen. "But engaging in the civil wars, he was killed in one of Montrose's battles, and his little property was lost to his family. His son *Thomas*, then an infant, was brought up by his relations and under very untoward circumstances, occasioned by the persecutions of the times, he succeeded in requiring a knowledge of the first branches of mathematics, sufficient to enable him, at a later period, to establish himself as a schoolmaster at Crawfordsdyke. He died in February, 1734, aged 92, and Margaret Sherar, with whom he had "lived in marriage fifty-five years," died in March, 1735, aged 79. They left two sons; *John*, the elder, assisted his father as a teacher: he settled at Ayr, and afterwards removed to Glasgow, where he was employed in directing farming improvements. "He drew plans of land neatly and accurately, which was a rare accomplishment in those times." He died in 1737, leaving a MS. survey of the river Clyde, which was afterwards published by his brother. *James*, the second son, engaged in the trade of general dealer at Greenock. He also possessed taste in mapping land, but the necessary attention to the business of his shop, left him

ments of a common education at the public school of his native town. But with him "nature appeared delighted to play an after-game as well as fortune," for his extreme delicacy of health was as unfavourable for mental as it was for bodily exertion, and on completing a desultory attendance, he left school in his thirteenth year, without having given any indications of a capacity beyond that of the common grade of his youthful associates. He subsequently derived a slight knowledge of the introductory rules of arithmetic from his father, and by sometimes accompanying him in his occasional surveys of land, he acquired a bias towards that employment.

During his visits to a maternal aunt, the wife of a brewer, at Glasgow, Watt became interested in the operations of a mechanic, who eked out a scanty subsistence by making and repairing fishing tackle, and the simple instruments used in mechanical drawing. By turns a cutler and whitesmith, a repairer of fiddles, and a tuner of "spinets," he was an useful man at almost every thing. He retailed nick-nacks of many kinds, and through dealing in spectacle glasses, he was dignified with the

few opportunities to exercise his abilities in that way. He became much respected by his townsmen, and served, in his turn, the office of a "Bailie," and was for twenty years a member of the "Town Council." "Misfortunes in trade and the decay of the faculties of his mind, occasioned his retirement from business some years before his death."—*Supp. Ency. Brit.* vol. iv. In the burial ground of the West Church, Greenock, is the following inscription, which records the year of his death, and other particulars of his family: "In memory of James Watt, merchant in Greenock; a benevolent and ingenious man, and a zealous promoter of the improvements of the town, who died 1782, aged 84. Of Agnes Muirhead, his spouse, who died 1783, aged 52; and of John Watt, their son, who perished at sea, 1763, aged 23. To his revered parents and to his brother, James Watt has erected this monument."

title of an optician. The instructions of such an artist could offer little present, and still less prospective inducement to any one for the sacrifice of the time, which was fixed as the price of their purchase. But as the employment demanded no robustness of frame for its exercise, Watt in his sixteenth year entered upon his new vocation, under the auspices of the spectacle-maker.

At the end of a servitude of not quite two years, he went to London, and succeeded in getting employment from a regular mathematical instrument maker. Here he saw methods of order and despatch in business, to which in his probation he had been a stranger. This, however, was acquired at a price to him beyond its value; "for his seat in winter, being near the door of his workshop, he caught a severe cold, the effects of which he felt at times until his sixtieth year, when the severe and distressing headachs which they occasioned, ceased to afflict him."

The metropolis had few attractions for so solitary a man as Watt, and he returned to his native town in little more than twelve months after he had left it; and soon after "he began to job on his own account," both there and at Glasgow; but at the latter place, in which he was more anxious to settle, a formidable obstacle presented itself in the shape of a corporation. He was not a burgess, and the rights of some of the trades were considered to be infringed by his fabrication of compass legs, repairing fiddles, and fishing rods; an offence which could only be atoned for by his removal beyond the city jurisdiction.

By dexterous management, Bishop Turnbull in the olden time had contrived to place the administration of the town affairs in the hands of the university; or, in the words of a local historian,

"the wily ecclesiastic had seized upon and destroyed the liberties of the town of Glasgow." The general claim to do as they pleased in the city, it is true, had been abandoned; but over the area occupied by their buildings and gardens, the power of the college council remained as absolute as ever. Into this, as an asylum, Watt was admitted; and by the kind offices of some of the professors, a room within the sacred precincts was allotted to him, in which henceforth he could transact his business, without even a fear of molestation from the sturdiest deacon of the corporation.

It was here, some time in 1759, that his attention was first directed to the subject of steam-engines, by a student, who although young, was distinguished for his attainments in the geometry of the ancients. The idea of applying steam to move carriages, was thrown out by Mr. Robison*, but

* John Robison, LL.D., was the younger son of a merchant who had retired from business, and lived at Baldernock, Stirlingshire, where he was born in 1739. He was intended for the church, but in the course of his studies he imbibed an aversion to it as a profession. He accompanied, as a tutor, the son of Admiral Knowles, in the expedition which co-operated in the conquest of Quebec; and on some promises of promotion, he went with his former pupil to Portugal. On his return to England, he was selected by the Board of Longitude to proceed to the West Indies, to observe the famous time-keeper, for which Harrison claimed the national reward of twenty thousand pounds. Being disappointed at his return of the expected pursership, he retired to Glasgow, and succeeded Dr. Black as lecturer on chemistry. His patron, Admiral Knowles, having received a high naval office from the court of Russia, Robison accepted of his invitation to accompany him; and act as his secretary. By the admiral's influence, he was nominated Inspector of Marine Cadets at Cronstadt, an appointment which he gave up, on being elected to the Professorship of Natural Philosophy in the University of Edinburgh, where he spent the remaining thirty years of his life, and continued his literary labours without intermission. The most important of these was a

he soon afterwards leaving college, and going with the expedition which reduced Canada, the scheme was given up. After an interval of two years, Watt attempted (1761-62) some experiments with a Papin's digester, (figure marked WATT L.) and by fixing to its lid a brass syringe, having a solid piston, he formed a kind of steam-engine. The vapour from the boiler, *a*, was admitted to the under side of the piston, *c*, by a cock, *o*, which also opened or closed the communication with the atmosphere. When steam flowed from the boiler into the cylinder the piston was raised up, and lifted a weight, *i*, with which it was loaded; and the steam from the boiler being then interrupted, and a communication with the atmosphere opened, the piston fell to the bottom of the syringe*. An impression of danger from bursting the boiler, the difficulty which it was obvious would be experienced to make the joints steam-tight, and a waste of steam taking place, from no vacuum being made to assist the rise of the piston, made him not only relinquish the thought of a machine on this principle, but to suspend his experiments.

series of papers which have been lately collected into four volumes, under the title of *Elements of Mechanical Philosophy*, a work of great merit. This contains an excellent history of the steam-engine, nearly to the period of the Doctor's death (1805), to which Mr. Watt added notes, giving a narrative of the steps by which he was led to his great improvements.

"Doctor Robison's person is described as handsome, and his countenance as prepossessing. He was a good linguist, an excellent draughtsman, and an accomplished musician. His conversation was always energetic and interesting, and sometimes poetical. His mind was imbued with the genuine spirit of the philosophy he taught, and nobly elevated above the mean jealousies of rival ambition."

* The figure is copied from Leupold's Theatrum Machinarum, Fig. 27, vol. iii., published thirty-five years before the trial in the text.

At the lapse of other two years the subject was again presented to his observation, by a model of an engine constructed on Newcomen's principle, which Professor Anderson* had sent him to repair.

* John Anderson, A.M., F.R.S., F.A.S., a distinguished Professor of Mechanical Philosophy in the University of Glasgow, was born at Roseneath, Dumbartonshire, in 1726. His father, who was minister of the parish, died while he was very young, but he was brought up and carefully educated by an aunt. In 1745, when Stirling was besieged by the Pretender, he acted as an officer in the regiment which was formed by the inhabitants to assist in its defence; and from this circumstance he imbibed a strong predilection for the military art, and made considerable progress in the study of fortification. He planned and superintended the works erected for the defence of the town of Greenock against the French sea-captain Thurot. "He invented a six-pounder field-piece, the recoil of which was stopped by the condensation of common air within the body of the carriage;" this being rejected under rather unpleasant circumstances by the Duke of Richmond, then Master-General of the Ordnance, its inventor in disgust went to Paris, and presented it to the National Convention. The legislators, with more tact than "the patriotic Duke," accepted his offering, and ordered his model to be hung up in their hall, inscribed as "the gift of science to liberty." And they pleased the Professor by permitting him to make experiments with it, at his own expense, in the neighbourhood of Paris. During his residence there, Louis XVI. was brought from Varennes, and the Professor is said to have stood on the altar of liberty with the Bishop of Paris, and sung Te Deum when the unfortunate king took an oath to the constitution. And when the Emperor of Germany established a line of troops on his frontiers, to guard against the introduction of French principles and newspapers, he suggested the plan of making small balloons of paper, varnished with boiled oil, and filled with inflammable air, to which the dreaded manifestoes might be tied. When the wind was favourable for Germany, these revolutionary heralds were sent off, and descending in that country were picked up by the people. They carried a small flag or streamer, bearing an inscription of which the following is a translation:—

"O'er hills and dales and lines of hostile troops I float majestic,
Bearing the laws of God and nature to oppressed men,
And bidding them with arms their rights maintain."

At this time he knew nothing of the mechanism except from the descriptions given by Belidor and Desaguliers, and their illustrations were in many points obsolete, and in others contradictory and inconsistent.

When he set, however, about repairing the model, as a *mere mechanician*, he found that the

In turning from these vagaries, which he lived long enough to regret, he is presented to us in the character of a warm and disinterested lover of his country, an ornament to it by his talents and genius, and entitled to its grateful remembrance for being *the first who afforded the means of instruction in philosophy to the working classes.* He visited workshops, to draw from mechanic operations illustrations of the doctrines he taught in his lectures; and he invited artisans to attend his discourses, to hear an explanation of the principles on which their manual operations depended. These familiar and popular lectures he delivered twice a week during the college session, for many years before his death, and he made them permanent, by bequeathing nearly his whole fortune for the endowment of an institution in which philosophy was to be taught in its application to the arts, in a manner adapted to the comprehension of the artisan. This establishment has lately acquired great celebrity, as the parent of Mechanics' Institutions. Doctor Garnett was the first who, under the founder's will, continued his lectures for a few seasons. Doctor Birkbeck next gave two or three courses of lectures, but to Doctor Ure it appears is mainly due the honour of giving form and stability to the institution; who has through good and adverse times, for twenty years, devoted his labours to promote its usefulness and prosperity.

"Professor Anderson was in the custom of delivering his lectures extempore, a practice which is now but little followed. As a popular lecturer, he was unrivalled. His manner was easy and graceful, his command of language unlimited, and the skill and success with which his manifold experiments were performed, could not be surpassed. His free and independent mind was exhibited in every action of his life; and enthusiastic in his profession, his whole ambition and happiness consisted in making himself useful by the dissemination of knowledge. He was the author of some detached works of merit, and of numerous papers in the various periodical works of the time. He died at Glasgow in 1796."—*Glasgow Mechanic's Magazine*, vol. iii., p. 4.

boiler (about nine inches in diameter) although sufficiently large when compared with those used in practice, could not supply steam fast enough for the two-inch cylinder which had a six-inch stroke, and although the vacuum was very imperfect, an enormous quantity of injection-water was required to produce it. He rightly attributed this to the cylinder of the model exposing a greater surface in proportion to its capacity than the larger cylinders, and the cylinder of brass cooled faster than the cast-iron ones of working engines. Operating with a still more imperfect vacuum, the boiler supplied steam to move the piston regularly, and the injection-water required was moderate.

Thinking to diminish the waste of steam by using a material which would cool slower than brass, he made a cylinder of wood*, (six inches diameter and twelve inches stroke,) soaked in linseed oil and baked to dryness. This was not only objectionable on account of its less durability, but it condensed more steam in proportion than working engines. In fact, the cylinder itself heated the water which it contained, and produced vapour, which in part resisted the pressure of the atmosphere, and thus diminished the power of the engine. A better vacuum was easily produced, by

* In an engine Brindley erected at Newcastle-under-Lyne, he introduced wooden cylinders, made in the manner of coopers' ware, instead of iron ones, as being cheaper and more easily managed in the shafts. He also substituted wood for iron in the chains which worked at the end of the beam. He had formed designs of other improvements, but he was discouraged by obstacles thrown in his way from proceeding with them. In another instance he surrounded his metal cylinders with a wooden case, and the interval was filled with light wood ashes, and by this and using no more injection than was necessary for the condensation, he reduced the waste of steam to almost one-half. *Rees's Cyclo.* vol. xxxiv. Art. Steam-Engine.

using a larger quantity of injection water; but then the cylinder by this means was cooled so much, as to require steam to heat it again, in quantity out of proportion to the power gained by the more perfect condensation: in ordinary cases it required a quantity of steam equal to several times the capacity of the cylinder to heat and fill it every stroke; he saw that it was in consequence of these effects that the old engineers did not reduce the internal heat of their cylinders below 142° or 174°, by which they could not place more than six or seven pounds weight on each inch square area of their pistons *. Suspecting that there was some

* The same things had occurred to Smeaton in an engine he erected for the New River Company, in 1767.

"He considered, in calculating its proportions, that the stoppage of the water at every stroke, as well as putting the lever-beam, piston, heavy-rods, and chains from a state of rest into motion twice at every stroke, was a great loss of power in the common engines; he therefore determined to work the engine slower, and with larger pumps, and to put upon the piston all the load it would bear. To reduce the velocity of the column of water still more, he would place the fulcrum of the beam out of the centre, and make the stroke of the piston nine feet, whilst the pump which lifted thirty-six feet, should work with only a six feet stroke. This arrangement obliged him to employ a *long narrow* cylinder of only eighteen inches diameter, and from this he also expected to obtain other advantages, viz., that every part of the steam, being *nearer the surface of the cylinder*, would be more *readily condensed*, and in consequence that *a less quantity of injection-water* would serve the cylinder, which would itself be more heated. He therefore placed a load of ten and one-third pounds on each inch on the piston, and having once seen a common engine struggle under this burden, he thought himself quite secure under those advantages; but how great was his surprise and mortification to find, that instead of requiring less injection-water, it required more, and that two men were obliged to assist to raise additional injection-water by hand, to keep the engine in motion at the same time that the *cylinder was so cold*, that he could keep his hand upon it, and bear it for a length of time in the hot well. He tried many experiments, without any good effect,

error in the usual estimate of the expansion of water into steam, he ascertained by a few simple experiments, that a measure of water is dilated into eighteen hundred measures of steam, capable of resisting the pressure of the atmosphere*; and that when water boils under pressures greater than that of the atmosphere, if the temperatures proceeded in an arithmetical ratio, the expansive power of the vapour increased in some geometrical one.

During these experiments, his curiosity had been excited by the great quantity of injection-water required to condense the steam; and also by the great heat the water acquired by the conden-

until he altered the fulcrum of the beam so much as to reduce the load on the piston to eight pounds and a quarter; though this shortened the stroke at the pump, and the engine went so much quicker, as to raise more water, consume less coals, take less injection-water, the cylinder became hot, and the injection-water came out at 180° Fahr., and the engine did its work better and more pleasantly. This at once convinced me," says he, "that a considerable degree of condensation of the steam took place in the cylinder, and that I had lost more this way by the coldness of the cylinder, than I had gained by the increase of load. In short, this single alteration seemed to have unfettered the engine."—*Rees's Cyclop.* vol. xxxiv. Art. Steam Engine.

* Smeaton weighed a Florence flask of four inches diameter, first when it was perfectly dry and empty, and afterwards when it was filled with water; then pouring out all the water except a small quantity, he put the flask on the fire, and made it boil until the last drop had disappeared, and at that instant he closed the mouth of the flask, to retain the steam which was in it. He weighed the flask to ascertain the difference of weight between it when filled with water, and by steam equal to the pressure of the atmosphere; deducting the weight of the flask from each experiment, it gave the proportion of the quantity of water converted into steam, and the content of the flask gave its expansion. His first trial made it $\frac{1}{2435}$; but, suspecting a source of error, he reduced his estimate to $\frac{1}{1800}$.—*Ibid.* Art. Steam Engine.

sation. By means of a glass tube inserted into the spout of a tea-kettle, he allowed the steam to flow into a glass filled with cold water, until it was boiling hot. The water was then found to have gained nearly a sixth part by the steam which had been condensed to heat it, and he drew the conclusion, that a measure of water converted into steam can raise about six measures of water to its own heat, or eighteen hundred measures of steam can heat six measures of water. "Being struck," says he, "with this remarkable fact, and not understanding the reason of it, I mentioned it to my friend Dr. Black*, who *then* explained to me his doctrine of latent heat, which he had taught some time before this period, (summer of 1764); but having been occupied with the pursuits of business, if I had heard of it I had not attended to it, when I thus stumbled upon one of the material facts by which that beautiful theory is supported."

These interesting pursuits were not, however, those in which he was at this moment most deeply interested. The influence of a tender attachment drew him from retirement, and for a time from philosophy. A single life, and a college room,

* "Dr. Robison," says Mr. Watt, "qualifies me as the pupil and intimate friend of Dr. Black, and goes the length of supposing me to have professed to owe my improvements upon the steam-engine to the instruction and information I had received from him, which certainly was a misapprehension; he is also mistaken in his assertion, that I had attended two courses of the Doctor's lectures. Unfortunately for me, the necessary avocations of my business prevented me from attending his, or any other lectures at college." "The improvements proceeded upon the old established fact, that steam was condensed by the contact of cold bodies; and the later known one, that water boiled at heats below 100°, and that a vacuum could not be obtained, unless the cylinder and its contents were cooled every stroke to below that heat."—*Robison's Mech. Philos.*, vol. ii., p. 6.

were now exchanged for the society of his maternal cousin, and a shop in the salt-market; and his wife being the daughter of a freeman, the opposition he experienced at his outset was also at an end. His civility and attention gained him friends, and his business increasing, he was soon in a situation to require the labours of an assistant and apprentice.

CHAPTER TENTH.

"WE CAN NEVER LOOK ON THIS WONDERFUL MACHINE, WITHOUT RECALLING THE CLASSICAL TALES OF THE GIANTS, AND REALIZING THE FEATS OF THE SONS OF TITAN, AND THE LABOURS OF HERCULES."—*James Ewing.*

INGENIOUS as Watt's experiments certainly were, they are now chiefly to be remarked as giving a new direction to his views regarding the defects of Newcomen's engine. From their results, he saw that in order to make the best use of steam, it was necessary that the *cylinder should always be as hot as the steam which entered it.* And also, that all the water that was formed by the condensed steam, and the injection-water likewise, should be cooled down to 100°, or lower where that was possible.

In looking to what had been done, or suggested by others, he had little to guide him in this inquiry. A rude help to his ingenuity might have been derived from some of the most common experiments with the air-pump; but at the moment when his sagacity had pointed out the direction of the path, his imagination did not enable him to follow it.

He had yielded to the difficulty, when early in 1765, "in one of those moments when the hea-

venly spark of genius shone with brightness in his mind, the idea broke in upon him," that if a *communication were opened between a cylinder containing steam and another vessel which was exhausted of air, the steam would immediately rush into the empty vessel, and if that were kept very cool, by an injection or otherwise, the steam would continue to enter until the whole was condensed. And if an air-tight cover were placed on the cylinder, steam might be admitted to depress the piston into a vacuum instead of the atmosphere.* ADMIRABLE INVENTION!

When once the idea of separate condensation was started, minor improvements followed in quick succession. He imagined that the orifice for the piston-rod could be kept air-tight by means of a stuffing-box; and as it was obvious water could not be introduced to make the piston steam-tight, for if any of it found its way into a hot cylinder it would be converted into vapour, (as in some of his experiments), he should employ wax and tallow as lubricating substances. He also thought that, by surrounding his cylinder with a casing of some substance which would prevent its heat from being abstracted by the circumambient air; and the air which was disengaged from the water, or found its way into the cylinder, he could extract by a pump, and by the same means he might employ the condensing vessel of the water which was produced by the injection and the condensation of the steam, or he would allow it to fall through a pipe thirty-four feet long into a pump or well, as practised by Newcomen and others. Thus, step by step, in the course of one or two days, in the eye of his mind, the exquisite conception was complete *.

* "About the time that Mr. Watt was engaged in bringing

Hastening to submit his ideal mechanism to the ordeal of experiment, he enclosed, by pieces of

forward the improvement of the engine, it occurred to Mr. Gainsborough, the pastor of a dissenting congregation at Henley-upon-Thames, and brother to the painter of that name, that it would be a great improvement to condense the steam in a vessel distinct from the cylinder, where the vacuum was formed, and he undertook a set of experiments to apply the principle he had established, which he did by placing a small vessel by the side of the cylinder, which was to receive just so much steam from the boiler as would discharge the air and condensing water, in the same manner as was the practice from the cylinder itself, in the Newcomenian method, that is by the snifting valve and sinking pipe. In this manner he used no more steam than was just necessary for that particular purpose, which at the instant of discharging, was entirely uncommunicated with the main cylinder, so that the cylinder was kept constantly as hot as the steam could make it. Whether he closed the cylinder as Mr. Watt does, is uncertain; but his model succeeded so well, as to induce some of the Cornish adventurers to send their engineers to examine it; and their report was so favourable, as to induce an intention of adopting it. This, however, was soon after Mr. Watt had his act of parliament passed for the extension of his term; and he had about the same time made proposals to the Cornish gentlemen to send his engine into that country. This necessarily brought on a competition, in which Mr. Watt succeeded; but it was asserted by Mr. Gainsborough, that the mode of condensing out of the cylinder was communicated to Mr. Watt by the officious folly of an acquaintance, who was fully informed of what Mr. Gainsborough had in hand. This circumstance, as here related, receives some confirmation by a declaration of Mr. Gainsborough the painter, to Mr. T. More, late secretary to the Society for the Encouragement of the Arts, who gave the writer of this article the information; and it is well known that Mr. Gainsborough opposed the petition to parliament through the interest of General Conway."—*Hornblower, in Gregory's Mechanics*, p. 362, vol. ii., first edition. On this statement, a writer in the *Edinburgh Review* observes, "We believe and hope, for the sake of the memory of a very respectable man, that the conversation is not accurately represented.—It remains upon record that Mr. T. More was examined as a witness on the trial of a cause of Bolton *versus* Bull, in 1792, at which time Mr. Hornblower himself was also examined as a witness, but on the opposite side from Mr. More.

tin-plate, the ends of the brass cylinder, *a*, of a syringe one and three-quarters inch in diameter, and ten inches long. A valve was fixed at the lower orifice of a longitudinal perforation made through the axis of the piston-stem, *b*, which was placed to move downwards. Two tin-plate pipes, *c*, *d*, about one-sixth of an inch in diameter and ten inches long, placed perpendicularly, communicated at top with a short horizontal pipe, *e*, of large diameter, shut at its upper end, having a valve, *i*, opening upwards; these pipes were connected at bottom with another perpendicular pipe,

Mr. More, on this occasion, was asked, whether he had read the specification of Mr. Watt's invention, and whether, in his opinion, it contained a disclosure of the principles of the steam-engine? To this question he answered, 'I am fully of opinion that it contains the principles entirely, clearly, and demonstratively.' He was then asked, 'Did you ever meet with the application of these principles before you knew of Mr. Watt's engine?' his answer was, 'I do declare I never saw the principles laid down in Mr. Watt's specification, either applied to the steam-engine previous to his taking it up, or ever read of any such thing whatever.' It is not easy to reconcile these two answers given by that gentleman on his oath, with the words that Mr. Hornblower has put into his mouth. Mr. Gainsborough's idea, whatever it was, was posterior by more than twenty years." (?) p. 328, vol. xiii. We know not if the claim which is put forth in the above extract, is the same as that alluded to by the late venerable Professor Jardine. "I happened," says he, "to be tutor to Dr. Roebuck's sons at that time (when Watt was at Kinneil); I had then the pleasure of seeing the experiments on a great scale, which were carrying on. This accidental circumstance, and this opportunity, connected me so much with what was going on, that when they were completed, I was asked by Mr. Watt to go with him to Berwick, when he went to give in a specification of his invention before a Master in Chancery, previous to the obtaining of a patent. And many years afterwards, when a groundless and frivolous charge was brought against Mr. Watt, *by a person who claimed a share in the invention*, I was called to give evidence of what I knew of this in Chancery. It is needless to add, Mr. Watt was triumphantly victorious."

a, about an inch in diameter, and ten inches long; this was furnished with a piston, *x*, and served for a pump; a pipe, *s*, conveyed steam from a boiler to the top and bottom of the cylinder.—(Engraving marked WATT L., fig. 2.)

Having placed the pistons at the bottoms of their respective vessels, he admitted the steam from the boiler to flow into the cylinder until it escaped through the perforation in the stem, and through the valve into the condenser. When he thought all the air was expelled from these vessels, he shut the steam-cock, and drew up the piston in the small pump; the steam rushed into them was condensed, and a vacuum being thus produced above the piston, and its under side being open to the boiler, the piston in the cylinder rose and lifted a weight of eighteen pounds which was hung to the lower end of its rod. He again shut the exhaustion-cock, and admitted steam, and the operation was repeated; and thus a *hot cylinder* and *a perfect vacuum*, which all previous engineers had wished for, sought for, but abandoned as hopeless, were produced by means almost rivalling those of nature herself, in their simplicity.

So favourable a result, with such an imperfect apparatus, gave him confidence to attempt a second experiment. He knew the varying and often most contradictory results from an engine on the scale of a model, and one of dimensions adapted to practice; and although in his experiments the smallness of his cylinders gave a great advantage to those of large proportions, yet other parts of his mechanism might be differently effected. A large model, however, required a large room, and his usual place of business offered no convenience of constructing a machine of any

magnitude, and yet conceal its parts, and preserve the secret of its principle.

He had assisted one of his friends in establishing a small pottery at a short distance from the town, and held a share in its property. He appropriated one of the rooms of this "Delft Work" to his purpose, and, assisted by his ingenious apprentice, John Gardiner, he began the construction of his second model on a scale of some magnitude. The cylinder had a diameter of nine inches, and was enclosed by a casing of wood, and its piston-rod was attached to a balanced lever. An accident terminated his operations with this engine; the beam broke, and neither his leisure nor his means enabling him to repair the damage, the model was thrown aside, and his project was suspended. He states, however, in his narrative, that the saving of steam, and the increase of power which it indicated, satisfied his expectations.

His practice as a land-surveyor, to which he was devoting himself, introduced him to employment as an engineer. He made various surveys for lines of canal, and he was intrusted with the superintendence of a short one, which was formed between the Monkland collieries and Glasgow. But whether it was from a wish not to interfere with those arrangements to which he had pledged his time, or the fear of the opposition which he might encounter, or a diffidence in the project, or himself, that for three or four years prevented a disclosure of his discovery, even to his friends, is not known; but he seems to have felt that a fair trial could only be given to his invention by the erection of an engine on a large scale, and, above all other mechanisms, the steam-engine, in its simplest form, was one of the most costly; and who, in this community, could he hope to induce to hazard

some thousands of pounds on the chance of a mere experiment, with a machine then little used, and less understood in his neighbourhood? for, it should not be forgotten, that the system of commercial adventure was very different then from what it is now. Pedlars who at this time were gathered to their fathers, slept in dignity, with "merchant" inscribed on their tomb stones, and their higgling spirit was inherited by their children. Some small fortunes had been made in the foreign trade, few had been risked in any; and a solitary instance was all that could be held up as a stimulus to excite the hope of a fortune being realized by a manufacturing speculation.

CHAPTER ELEVENTH.

"TO EXTENT AND VARIETY OF KNOWLEDGE WAS JOINED A KINDNESS AND LIBERALITY WHICH MADE THAT KNOWLEDGE THE PROPERTY OF THE PUBLIC, AND AVAILABLE ON ALL OCCASIONS TO THE ADVANCEMENT OF THE ARTS AND MANUFACTURES OF HIS COUNTRY."—*Kirkman Finlay.*

WHILE Watt had been silently employed in imbodying his ideas, the attention of the inhabitants of the west of Scotland was fixed on the operations of an English physician, a man of original and splendid enterprise, who had become celebrated as a projector of rare and excellent fortune in some apparently even unpropitious speculations.

Doctor John Roebuck was a native of Sheffield, in which town his father was a manufacturer in easy circumstances. Having the choice of a profession left to himself, he began the study of medicine at Edinburgh, and became an expert chemical manipulator. At Leyden, where he completed his studies, he took his degree, and on his return to England, he practised as a physician at Birmingham. The avocations of an extensive practice were not, however, so exclusive as to engage his whole attention, and he resumed with ardour his chemical inquiries. In conjunction with a

friend, he soon afterwards erected an extensive laboratory, and there he applied on the great scale, for the purposes of the manufacturer, some of the economical processes to which his experiments had directed him. The result of his researches on sulphuric acid, then of a high price, led to an entire revolution in the value and preparation of this substance. From its manufacture, which was long conducted with impenetrable secresy, at Prestonpans, the golden harvest which he reaped was so ample, that he abandoned the practice of the healing art as a profession*.

* JOHN ROEBUCK, M.D. F.R.S., was born in 1718. After leaving the grammar-school of Sheffield, he was placed under the tuition of Dr. Doddridge at Northampton, where he laid the foundation of that classical knowledge for which he was afterwards much distinguished. With his fellow students, Jeremiah Dyson, afterwards well known in the political world, and Akenside, the poet, he contracted friendships which continued during their lives. At Edinburgh he displayed great logical and physical acuteness, and was noted for ingenuity and resource in debate. The sagacious Porterfield observed and encouraged his rising genius, and here he formed friendships with Hume and Robertson, the historians. He left Edinburgh in 1744, and studied at Leyden the usual time for his degree; on his return he settled at Birmingham. His education, talents, and interesting manners, were well calculated to promote his success as a physician, and he met there with great encouragement, and was soon distinguished in that town and the country adjacent, for his skill, integrity, and charitable compassion in the discharge of the duties of his profession. In his manufacturing laboratory he practised certain methods of refining gold and silver, and particularly an ingenious method of collecting the smaller particles of these precious metals, which had been formerly lost in the practical operations of many of the manufacturers. In 1747 he married Miss Ann Roe, of Sheffield, a woman of a great and generous spirit, whose temper and disposition equally fitted her for enjoying the prosperous circumstances of their early life, and for bearing her share in those anxieties and disappointments which shaded the latter periods of their lives. A Dr. Ward was the first in England who established a profitable manufacture of

The banks of the little river which formed the most northern boundary of the Roman empire in

oil of vitriol, but from the great expense of glass vessels, and the frequent accidents to which they were liable in the process, the acid was high in price. Roebuck substituted leaden vessels of great size, for the glass ones, and by this and other improvements reduced its price from sixteen pence to four pence a pound. This was one of the most lucrative establishments of the time; but, instead of taking out a patent, he chose the better plan of conducting the process in great secresy, which was persevered in successfully for a great many years. Carron was his greatest work; and he was the first, who by means of pit-coal refined crude or pig-iron to make bar iron of it, instead of doing it by charcoal, as formerly practised. The best and certain proof of his judgment and science, is the prosperous state of these works, and their having served as a model to others of great magnitude in different parts of Scotland, which may be said to have sprung from this as a parent. It is painful to retrace the unhappy consequences of his ruinous speculation in the coal and salt works at Kinneil. The result was, that after many years of labour and industry, he sunk not only his own, but the considerable fortune brought to him by his wife, the profits and property in all his speculations, and what distressed him most, great sums borrowed from his relations and friends which he never was able to repay. During the last twenty years of his life, he was subjected to a constant succession of hopes and disappointments, and to a course of labour and drudgery. As the price of so many sacrifices he was only enabled to draw from his colliery, (and that by the *indulgence* of his creditors,) a moderate annual maintenance during his life. At his death, his widow and family were left without any provision whatever for their immediate or future support, and without the smallest advantage from the extraordinary exertions and meritorious industry of her husband.

These works, of no advantage to himself, and which ruined his family, were attended with the most beneficial effects upon the trade, population, and industry of Scotland. At his death, not less than four thousand persons were *directly* employed in establishments which he founded, and their wages alone amounted to about eighty thousand pounds per annum. Had each of those persons allowed their common benefactor, in his old age, eighteen pence per annum only, he would have received more than he did from the compassion of his creditors. But it was not solely by his individual establish-

Britain, and the scene of many memorable events in Scottish history, a bleak and steril tract, was chosen as the site of a stupendous experiment. It offered an abundant supply of water to impel machinery; in its neighbourhood were inexhaustible mines of coal, and quarries of ironstone, and lime; and its position on the strip of land that separates the estuaries of the Forth and Clyde, opened an easy water-communication to every market on the German and Atlantic oceans. Here, by the assistance of a little band of relations and friends, who intrusted their fortunes to his judgment and honour, he began his operations on a scale of magnitude, at that time unknown in commercial adventure. The Carron Works

ments that his services to the country should be estimated, but other things necessarily connected with them; and among others, by creating a spirit of enterprise and industry before his time not known in Scotland, which soon pervaded other departments of labour, and gave birth to many other useful projects.

The taste for classical studies which he carried with him and improved in every period and every situation, became his favourite resource, and one of the chief enjoyments of his life. Possessing the happy talent of turning his mind from serious and fatiguing to elegant and recreating pursuits, he returned from the laboratory or coal pit, and drew relaxation and solace from the stores of classical learning. The amiable disposition of sensibility, humanity, and generosity, which strongly marked his character in the general intercourse of society, were peculiarly preserved and exercised in the bosom of his family, and in the circle of his friends. In the various relations of husband, father, friend, or master, it would not be easy to do justice to his character, or to determine in which of them he most excelled. Nor must it be forgot, for it reflected much honour on his benevolent heart, that his workmen not only found him at all times a kind and indulgent master, but a skilful and compassionate physician, who cheerfully visited the humblest abodes of poverty, and who attached them to his service by multiplied acts of kindness and generosity.—*Memoir by Jardine.*

appeared like the immense arsenal of a great nation, rather than a manufactory erected by a few individuals in the prosecution of an experiment to introduce an improvement into the smelting of iron.

The successful termination of this undertaking left him to seek a fresh field for his exertions; and if the one which quickly presented itself was pregnant with danger and surrounded with difficulties, it held out a more splendid reward than any even of those in which he had so triumphantly succeeded.

The estate of Kinneil, a few miles from Carron, contained extensive beds of coal, in which mines had been sunk, and worked for generations; but they had seldom produced any thing to the noble house of Hamilton, who were lords of the domain; and the adventurers who from time to time attempted to explore them, had as often desisted from the undertaking with loss. Roebuck was satisfied that the quality of the coal was superior to any in the district; he knew how much success in projects of this kind depended on the possession of ample means; and his inimitable tact of operating on a vigorous and steady system, was almost in itself sufficient to inspire him with more than his usual confidence of good-fortune in an enterprise in which he traced the failure of others who had preceded him, to their not possessing his accidental advantages. His presence at Kinneil, to which he removed from Carron, quickly infused a new spirit into every thing around him.

Watt, who had become known to Roebuck as a surveyor, appears to have reserved his invention for his patronage—to have looked to him as the only person whose experience enabled him to judge of the value of his improvement—who

knew the importance of the mechanism it was made upon—who had the means, and wanted not the spirit to expend them in bringing his invention, if it were practicable, to a bearing. Roebuck consented to be at the expense of an experimental machine, on a large scale, and Watt accepted of his invitation to construct it under his inspection.

In the winter of 1768, in one of the out-houses of the mansion, Watt, with Gardiner his assistant, began the formation of his third model. In this the cylinder was eighteen inches in diameter, and formed of block-tin. As might be expected, the greatest difficulty he experienced was the packing of the piston, so as to be steam tight, as it did not admit of water laying upon it as in the old engines. The condensation of the steam was produced by a jet of cold water in the eduction pipe. The cocks and sliding valves by which he regulated the steam and injection, were constructed in the same manner as those employed by Newcomen's and Savery's.

During the eight months which its ingenious inventor devoted to its erection, it was successively altered and improved, until it was brought to a considerable degree of perfection. And it cannot be a matter of surprise, that owing to its imperfect workmanship—to the material of which the cylinder was formed—to the want of experience in the proportions of the parts—and to its leaks—that the *vacuum* of the engine, on which depended its power, should be very imperfect. This however was not attributed to the right cause, but to the air which was introduced into the internal parts by the injection water.

Upon trial at a coal mine a few hundred yards from Kinneil, notwithstanding its imperfections,

Watt had the gratification of seeing his labour rewarded by the engine operating as he had anticipated. With all its faults, when compared with the common engines, the economy of fuel was prodigious; and what was then considered to be almost as great a point gained, the economy of water for condensation was not to be compared with that in the common ones. But above all it was important to Watt, as his patron was satisfied; and becoming a partner in the invention, he supplied the necessary funds to procure a patent, "for a saving of fuel in Fire Engines," and thus placed the invention beyond the reach of piracy. No drawing, however, accompanied the brief and vague description, which appears to have been drawn up from the experience gained in these experiments; and its distinguished author closed his career without giving to the public any details either of its subordinate mechanism or arrangement.

From this document we only learn, that "during the entire time the engine is kept at work, the cylinder is to be kept as hot as the steam which enters it, by a casing of wood, or by surrounding it by steam; and as a general rule not to suffer any substance colder than the air to touch it. In engines which were to be moved wholly or partially by the condensation of the steam, the steam is to be condensed in vessels distinct from the cylinder, though occasionally communicating with it, and these which he called the *condenser*, is always to be kept as cold, at least, as the air in its neighbourhood, by water or other cold bodies," and that the expansive power of the steam is to be used to press on the piston, in the same manner as the pressure of the atmosphere in Newcomen's engine. And he also said, "that in other

cases he intended to apply a degree of cold to the steam, not capable of reducing it to water, but of contracting it considerably, so that the engine shall be worked by the alternate contraction and expansion of the steam." But this excrescence appears to have been a mere thought, introduced probably to prevent an evasion.

Three other methods of employing steam are given in the same description. The first seems to have been suggested by his experiment with Papin's digester. And he merely says the vapour "which is to act on a piston, is to be discharged into the open air after it has done its office." No mechanism or further description is referred to. His scheme for procuring a rotary motion, although of the least value, is described with the greatest minuteness. This was a steam wheel in the "form of hollow rings or circular channels, with proper inlets and outlets for the steam, mounted on horizontal axles like the wheels of a water mill. Within them were placed a number of valves, that suffer any body to go round the channel in one direction only; in these steam vessels were placed weights, so fitted to them, as entirely to fill up a part or portion of their channels, yet rendered capable of moving freely in them. When the steam is admitted between these weights and the valves, it acts equally on both, so as to raise the weight to one side of the wheel, and by the reaction on the valves successively gives a circular motion to the wheel, as the valves open in the direction in which the weights are pressed, but not in the contrary. As the wheel moves round, it is supplied with steam from the boiler, and the vapour which has performed its office, may either be discharged by means of condensers, or into the open air." Of this mecha-

nism, no drawings or further description were given, but a reference to Amonton's wheel will readily explain its construction; the ideas are nearly the same *.

During his experiments, he had observed a property of elastic vapour, which, although almost as valuable in an economical view, as the condenser itself, does not appear, at the time, to have been of that importance, in his estimation, as to be included in his patent. In a letter (dated May, 1769, two months after he had enrolled his patent,) to his friend Dr. Small, who had settled at Birmingham, where he practised as a physician; he says, "I mentioned to you a method of still doubling the effect of steam, and that tolerably easy, by using the *power of steam rushing into a* vacuum, at present lost. This would do little more than double the effect, but it would too much enlarge the vessels to use it all. It is peculiarly applicable to wheel engines, and may *supply the want of a condenser*, where force of steam only is used. For open one of the steam valves, and admit steam until one-fourth of the distance between it and the next valve is filled with steam, shut the valve, and the steam will continue to expand and press round the wheel with a diminishing power, ending in one-fourth of its first exertion; the sum of the series you will find greater than one-half, although only one-fourth was used. The power indeed will be unequal,

* Many years after this, it is said he had a model of a similar contrivance made, in which the force of steam, acting in a circular channel against a valve on one side, and against a column of fluid mercury on the other side, was tried repeatedly at Soho, upon a scale of six feet, but was given up as several objections were found against it.—*Robison's Mech. Phil.* vol. iii.

but this can be remedied by a fly, or several other ways."

The period during which the experimental engine had been in progress, was the usual season of relaxation to Watt, from his surveying labours. On the return of summer, he was unexpectedly obliged to resume his poorly requited professional avocations*. For at this moment his patron began to feel the pressure of adverse circumstances, and the fire-engine project was suspended from time to time, until the tide should set more in his favour.

But the prospects of Roebuck, in his mining speculations, daily became more clouded. The quality of the coal did not answer his expectations; and, although he had introduced a better system, and brought expert and skilful workmen from England, where the subject was much better understood, the difficulties of getting even an inferior produce to the surface were daily increasing; his funds were gradually drying up; the capital he was obliged to withdraw from his concerns at Birmingham was quickly absorbed; the "leaden chambers" at Prestonpans, which to him had been coffers of gold, were his next great sacrifice; and, as necessity pressed, he parted with his share of the works at Carron. The enthusiasm which had before given a prosperous turn to schemes which but for that had been doubtful, became his ruin at last. In persevering to preserve, for his family, the wreck, at least, of the fortune he had expended, he flung the remainder away, which he

* Playfair's estimate of the profits from this employment in Scotland, about 1820, will probably better apply to this period. "Although," says he, "there are no great sums to be gained by such pursuits in Scotland, yet whenever there is business requiring such *diversity of talents*, the *remuneration* must be *adequate to keep a man from want!*"

never dreamt he was putting into hazard. It was in vain that he opened new channels in which to turn his minerals to account. Misfortune had laid her hand upon him, and his gold disappeared in seeking for coal, and was evaporated in his attempts to make salt, or burn lime. And through the same distressing embarrassments, he was induced to enter into a negociation to give up his connection with Watt, from which he might have reaped a harvest, greater than he had gathered from all his previous projects, lucrative as they were, put together.

CHAPTER TWELFTH.

"IF EXCELLENCE BE NEVER GRANTED TO MAN BUT AS THE REWARD OF LABOUR, A HISTORY OF FAILURES WILL INVARIABLY SHORTEN THE ROAD TO SUCCESS."—*Davy*.

Bitter as must have been Watt's disappointment at this termination to a connection from which he anticipated every flattering prospect, yet his extreme good fortune was never more signally displayed than in this occurrence, which to his family and himself appeared an almost irretrievable misfortune.

A friend of Roebuck's had, a few years before, been left in possession of forty thousand pounds, accumulated by an industrious father; and the first operations he commenced to expend it, showed that in him nature had marvellously united boldness with circumspection. If Roebuck had wider and more discursive views, and greater mental resources to carry them into execution, Matthew Bolton's expansion of mind was more valuable, as his apparently limited purpose arose from a greater knowledge of business, and a habit of perseverance. Roebuck was impetuous in his operations, that his active mind might turn to

something new; Bolton in success contemplated only an extension of that which he had succeeded in. The first delighted in the novelty of his projects, the other was equally pleased by an approach to greater perfection; and he felt that those speculations which honourably advanced his own fortune, by exciting competition, added also to the public wealth. But Roebuck, who was not unmindful of accumulation, was flattered by considering his operations as having their origin in a wish to benefit the country. Both enjoyed a high reputation for personal honour, and delighted in the bustle of society; only the founder of the iron trade of Scotland was mote anxious to be received in the high and refined circle he moved in, as an accomplished scholar and a man of science, than as an admirable practical chemist, and triumphant speculator. The princely master of Soho lived at his factory, and was pleased with the personal distinction which its extent and unrivalled excellence conferred upon him.

Watt, whose genius was to confer even honour on both was as opposite as the antipodes to either. His acquirements reached not beyond the limited knowledge necessary for the business of a surveyor; indolent from weak health, and procrastinating from an active but desultory imagination, he was incapable of giving to a series of details a prompt and steady attention. In his prime he possessed little curiosity, even on subjects which might have been considered vitally essential to his interests. Though not indifferent to the notice of beauty, and with manners calculated to win its regard, yet at every period of his life he was painfully embarrassed in the society of intelligent women. To fame he was absolutely insensible; and notwithstanding his

fondness of money, mercantile ambition never disturbed the monotonous tenour of his career. But nature had given him a fertile and exquisite invention*, great equanimity of temper, and all who approached him were charmed with the modesty of his mind. He shrunk from notice, as his inventions burst upon the public. He was formed to glide on the tranquil stream; for a ripple, by exciting his apprehensions, would deter him from proceeding. But accident, in aid of nature, now joined him to a colleague of tried nerve and energy. Bolton cared not to navigate a troubled sea, but, like a skilful pilot well acquainted with the landmarks, and secure in the trim of his vessel, he would tempt the storm rather than cripple his adventure.

To a man like Watt, so unfitted, from feeling and habit, to stand alone, nothing could have been more auspicious than his gaining the protection of two such men in succession. Obstacles were seen by either, only to be surmounted, and they both possessed, in an eminent degree, the master art of infusing into all around them a portion of their own matchless energy. Projectors themselves, they were considerate of his feelings, and knew how much the flow of thought in irresolute or hesitating genius is quickened by the kindness and condescension of a patron. Assisted by their experience,

* "The common and *ordinary habit of his mind*," says Professor Jardine, "*was invention*. Almost every object that attracted his attention, he conceived and represented as altered, changed, transformed, and applied in a different state to other purposes and other uses; and his imagination was ever fruitful in expedients and resources. When on his great and uncommon qualities, I cannot forget his modesty and simplicity of manners. Speaking once upon his great invention, I heard him say, 'that when it was analyzed, it would not appear so great as it seemed to be.'"

and animated by their generous approbation of what he had already achieved, he was roused and carried onward to impart greater perfection to his mechanism.

They who have urged a poverty of mind as indicated by his failing to give to his third model those proportions and details, which would have produced a more perfect action, are ungenerous, because they have imbibed this demeaning opinion from observing what may have been accomplished, since his time, by other mechanics in situations apparently more unpropitious than his own. But it is because they who have been thus put into the balance with him, began their career, after he had invented, that they could not experience difficulties so great as those he vanquished. A much greater accuracy of workmanship was required to ensure the proper action of his apparatus, than was demanded by engines of the common form; and at this time there were but one or two artists who could give the requisite truth of workmanship to the cylinders (of a couple of inches in diameter) of air-pumps. But Watt required cylinders of many thousand times greater capacity, and piston rods of comparatively immense size, all to be formed with as much nicety, and to act with equal precision, as these philosophical machines. *In fact, his engine was an air-pump of colossal dimensions,* in which, instead of the piston being lifted by hand, it was raised by steam; and, instead of making a vacuum in a small vessel containing half a cubic foot of air, after a long and a laborious operation, he exhausted a vessel, containing five hundred times that quantity, twenty or thirty times every minute, and each time raised a load equal to that which could be elevated by the power of hundreds of horses. To form a pro-

per notion of his mechanical position, it should, therefore, always be borne in remembrance, that in the beginning of his career, the tools and machinery, which are now so familiar to us, had to be invented and constructed, to manufacture the gigantic cylinders, and piston rods, and pumps, which he merely anticipated being called upon to proportion and combine.

At the time in which Roebuck's interest in the patent was transferred to Bolton, Watt was engaged in surveying the line of country, through which the Crinan canal was afterwards carried. The death of his wife, which happened when he was absent on this employment, breaking the strongest tie which had kept him in Scotland, by the advice of his friend Doctor Small, who had settled as a physician at Birmingham, he soon after, on Bolton's invitation, removed to Soho.

This celebrated establishment had not itself been long in existence. A few years before, the hill, from which it took its name, "was a barren heath, on the bleak summit of which stood a naked hut, the habitation of a warrener." On this a small building had been erected by an individual for an iron mill; but Bolton, who saw, in the little stream that rippled at the bottom of the hill, a supply of water to answer his purposes, acquired the land, and expended a sum more than equal to the half of his patrimony, in building workshops and dwellings for upwards of six hundred artisans. The water of the rivulet he had collected into a pool, and made it fall on a water wheel, which communicated motion to an amazing number of different implements and tools, by whose agency were fabricated, in the highest elegance and perfection, utensils of many kinds, in gold silver, tortoise-shell, and enamels, and

many vitreous and metallic compositions, with gilded, plated, and inlaid works. As the works had rapidly extended, the power of horses had been for a short time employed in aid of the water-wheel, but these had been superseded by an engine on Savery's construction. This pumped the water, that had moved the wheel, back into the reservoir; a mode of procuring a rotary motion then very generally resorted to *. The PRESIDING GENIUS of the place, who was furnished from the varied operations of this museum of mechanical wonders with the highest entertainment, as well as most lucrative employment, kept hospitality in a mansion on the other side of the hill, which he had surrounded with a beautiful garden, having the charms of shady groves, velvet lawns, and sparkling water.

Watt was now in a region celebrated for generations for the number and skill of its artisans, and where he had at hand every facility which the most expert workers in metals could bestow for the developement of his ideas. With regard to himself, he was placed in circumstances which left him at liberty to give his undivided attention to that which was now to be the ruling object of his life.

In the corner of Soho that was allotted for his future operations, he began the erection of his fourth model; which, however, on account of various obstacles, he did not complete until the

* Playfair says, "that the extra expense incurred by Bolton in building on a low swampy ground, to have the benefit of this stream, did not fall short of ten thousand pounds;" and he asks "how much has not the same Bolton contributed to the reduction of that stream, for which he paid so dearly; for one of the condensing engines, worth five hundred pounds, would turn more machinery than the brook which cost twice as many thousands."

latter end of the year 1774. When this was in action, those Cornish gentlemen who were interested in the mines, were invited to inspect its operation. The individuals who formed a deputation from the adventurers, for the purpose of observing this experiment, gave a very favourable report as to the effects of the patent engine with relation to the saving it made in fuel.

In describing this improved mechanism, it must be remembered that little is known of the details of this identical engine—and our illustration must be drawn from the machine in probably an improved stage; and the diagram will show, not the form and proportion, but the number of parts and their position in the earlier productions: *a*, balanced lever, or working beam, connected to the piston-rod *b*, by a chain *c*; *d*, the piston; *e*, the cylinder; *f*, the pipe leading from the boiler, which is also furnished with a box containing a valve, which by its rise or fall opens or shuts a communication between the boiler and cylinder; *k*, a valve, which also by its rise and fall opens or shuts a communication between the under side of the piston and the condenser *m*, by means of the eduction pipe *l*. The short pipe *n*, connecting the condenser with the air and water-pump *o*, has a valve at *p* opening into the pump barrel; in the piston of this pump are valves opening upwards, and at the top of the barrel is a short pipe, having a valve at its extremity opening outwards: *s*, is a common pump, with its rod attached to the balanced lever, to raise water from a well or cistern to replenish the box *t*, in which the condenser pipes and pumps are placed; the rod which draws the water from the mine, and which is also attached to the working beam is not shown;

y, axis of working beam; 1, 2, levers moving on joints and attached to the valves *i*, *k*, by means of rods working steam tight through the sides of the boxes; 8, 9, tappets or projecting pieces on the plug-rod. The pump-rod works through a stuffing box, so that the atmosphere is completely excluded from the interior of the engine: *u*, a space between the jacket and cylinder into which the steam is admitted by the pipe *f*, and from which it is introduced above the piston in the cylinder.

Previously to the engine being put in motion, the air which occupies its internal parts must be extracted. This is done by opening the valves and allowing steam from the boiler to flow into all the pipes and vessels, and the vapour being lighter than the air, expels it downwards through the eduction pipe into the condenser, and from that through the valves which open upwards in the air-pump. The valve *i* is then shut, and cold water being allowed to flow into the cistern, quickly condenses the steam in the condenser-pipes, and the steam under the piston rushing through the eduction pipe to restore the equilibrium, is also converted into water—the condensation in both vessels is so rapid, as in practice may be considered as quite instantaneous. The resistance at the under side of the piston being thus removed, the pressure of the steam issuing from the boiler forces the piston into the vacuous part of the cylinder.

The fall of the piston depressed one end of the working beam *a*; and as the air-pump rod is attached to the opposite end of the lever, its piston was raised to the top of its barrel, and the air and water which had flowed into the

condenser, and was prevented by the valve *p* from returning, is now lying above the air-pump piston.

But at the instant when the steam piston had reached to nearly the bottom of its cylinder, or had made its stroke, the tappets on the plug-frame *r*, struck the ends of the levers, or spanners, attached to the valves *g*, and *k*, and shut them.

The mine pump-rod is loaded with a weight or counterpoise, and it will be obvious, that to get the piston again into the place from which it has fallen, will require a force to be exerted equal to that which had depressed it, or some means must be resorted to, by which the depressing force may be removed or neutralized, so that the counterpoise (the use of which is to raise the plug-frame and the steam piston to the top of the cylinder *g*,) may have only their weight and resistance to overcome.

All these desiderata were obtained by a contrivance, remarkable for its simple and effective operation, at the moment when the fall of the plug-frame made one set of tappets act on the spanners and shut the valve *k*, and open the valve *i*, the steam which had depressed the piston is admitted through it beneath the piston, and an equilibrium being thus established between the upper and under side of the steam cylinder, the counterpoise on the opposite extremity of the beam raises up the steam piston, in a non-resisting medium. This adjustment may be instanced as one of the finest contrivances exhibited in the mechanism. During the rise of the steam piston by the operation of the counterpoise, the air-pump piston has, by the same means, been moved to the

bottom of its barrel. When the counterpoise has raised the piston to nearly the top of the cylinder, tappets on the plug-frame again strike on the spanners, or levers, attached to the equilibrium valve *i*, and shut it; and other tappets striking on the spanners attached to the valve *k* opens it. The steam below the piston now rushes into the condenser, and is, almost instantaneously, converted into water—this leaves a vacuum beneath the piston, and the expansion of the vapour on its upper side again presses it downwards into the cylinder, when the action of the plug-frame reverses the position of the valves as before, and the counterpoise raises the piston a second time to the top of the cylinder.

It should have been noticed when mentioning the raising of the steam-piston by the counterpoise, that during the descent of the air-pump piston by the same means, the water which had been produced by the condensation of the steam in the condenser, had fallen through the valve which separated the pump from the barrel, was lying at the bottom of this vessel; and the space between the surface of the water and the under side of the air-pump piston was filled with air which had entered it along with the water. This air being prevented from returning into the condenser pipes by the valve which opens from the condenser into the pump barrel, as the piston descends is compressed, and when it has by this means acquired the necessary density, its elasticity raises up the valves in the air-pump piston, and occupies the upper as well as part of the under portion of the pump, and as the piston also falls into the condensed water at the bottom of the barrel and

the action of the valve, *p*, preventing its return, it is forced above the valves, and is discharged along with the air.

In aid of the injection-water in forming the vacuum, Watt placed the condenser-pump, and the condenser, in a cistern of cold water, which, as it got heated, was allowed to flow off, and a fresh supply was drawn by the pump, *s*, from a well, or reservoir. The hot water which was pumped out of the condenser, into what was called the hot-well, *w*, was raised by another small pump into a cistern, from which the boiler was replenished with its water.

The method by which the piston-rod was kept steam-tight, and the entrance of the air prevented, was by means of a stuffing-box, inclosing a collar of hemp, and lubricated by tallow. This is similar to what is seen on the small air-pumps of that time, for a like purpose, and will be easily understood by an inspection of the figure in the plate marked Watt, figures 3 and 4.

It was now become of importance to ascertain the internal state of the condenser and cylinder, for, on a knowledge of the perfection of the vacuum in one, and the strength of the steam flowing into the other, depended the application of some of the regulating details. Watt connected a mercurial barometer to the inside of the pipe leading to the condenser, and he placed another barometer on the pipe leading from the boiler and opening into it. By the rise and fall of the mercury in the first, he ascertained, with great precision, the elasticity of the vapour remaining in the condenser, or the degree of its exhaustion; and by the rise or fall of the mercury in the steam-pipe barometer he had a similar precise measure of the strength of steam which pressed down the

piston; and it was, therefore, easy to calculate the power of the engine; for, if the force of the steam from the boiler raises the mercury to a height of thirty inches in the barometer, then he knew that this is equal to the mean pressure of the atmosphere; and that steam of this force will press with a weight of fifteen pounds upon each square inch of the surface of the steam-piston. And if all the steam and air were perfectly withdrawn from the other side by the action of the condenser and its pump, then the piston, falling into the vacuous part of the cylinder, with this weight, would lift an equal weight placed at the opposite end of a balanced lever, or working beam. But in practice, notwithstanding every care, a portion of air and vapour is always present in the condenser. The elasticity of this air, or the force with which it resists the pressure of the steam on the piston, is shown by the height at which the mercury stands in the condenser barometer; this of course must be deducted from the height of that in the other baromter, and the remaining height of mercury is that which shows the power by which the piston falls, or the weight that would be raised at the other end of the lever, supposing there were no other resistances than that arising from the imperfect extraction of the vapour and air in the condenser. This, however, is but a small part of the loss of power; for from the friction of the steam and condenser-pistons, and force required to open and shut the cocks, not more than seven or eight pounds weight can be raised by the force of fifteen pounds on the piston. So that more than a half of the whole power of the steam is wasted in giving motion to the mechanism.

It will be seen that with cylinders of the same size, and of equal perfection of workmanship, the

loss from friction was greater in the new than in Newcomen's engines; but then, in Newcomen's, five or six times the quantity of steam which filled the cylinder was required each stroke, and this arose from the mode in which the steam was condensed; but, in the new engine, not more than a quantity of steam equal to 1¼ of the capacity of the cylinder was required each stroke.

The heat of the furnace under the boiler was rudely regulated in both machines by a damper, which was open and shut by the person who had the charge of the engine.

Brindley preserved the heat of the cylinder by filling the interstice between it and its casing by dry wood ashes. By means of a small pipe proceeding from the steam-pipe, Watt introduced steam into this space; and thus kept even the external surface of his steam-vessel as hot as the steam moving the piston within it.

In the trials with this engine, Watt experienced many disappointments in his attempts to surmount two obstacles, apparently of no great difficulty; but in the formation and proportioning of the condenser and its pump, he was baffled at every step; and it was years after this before he was satisfied with this part of his invention. The construction of the piston also demanded all his ingenuity to make it move easily up and down, and yet be steam-tight, without having water lying on it, as practised in Newcomen's engines. On this he made numerous trials before he hit upon the method of forming the under part of the piston with a projecting rim, accurately fitted to the cylinder, but yet to allow it to move easily up and down, and wrapping hemp, or some other fibrous elastic substance, round the body of the piston, so as to fill up the space between it and the cylinder.

On the top of this he laid a plate also accurately fitted to the cylinder, and screwing this plate down to the projecting rim, the packing (or gasket) between them was pressed outwards to the surface of the cylinder, so tightly as not to allow steam to pass between it, yet permitting the piston to move easily up and down when lubricated with tallow. When employed with a well and truly bored and high-polished cylinder, this was a clever contrivance. By screwing the upper plate and rim nearer together, the gasket could be forced outwards at pleasure; and this gave the power of tightening it when it became leaky from attrition.

Five years of the term of the patent had now expired, and although the engine, which was now in action, was beyond expectation satisfactory, yet it was apparent that it ought only to be considered as an experiment. Even to bring it to this, however, great expenses had been incurred, and very great sums it was seen would be required to carry it fairly and further into practice. But the term of years that was to run, was so short as to forbid any large sum being embarked in the speculation: for at the moment when remuneration might be expected to follow, a rival might begin to manufacture the engines, and, starting with all the advantages arising from the experience of the patentee, without any of the preliminary incumbrance of the expenses of his first experiments, would thus be able, under unfair and unjust advantages, to contest for the field with the ingenious inventor.

These, added to the pre-eminent merit of the invention, formed the grounds of a petition which Watt was advised by his friends to present to parliament, for an extension of the term of his patent. The opposition to his claim, if not powerful, was

active; and it was now that the services of some of his philosophical friends were called into exertion. Among them, Doctor Roebuck was conspicuous. The petition was heard, and an act was passed, by which he had the sole privilege to manufacture and use his improved engines for twenty-five years after the date of his application; and, to crown his good fortune, Bolton became his partner in the manufacture of the engines, as well as in the share of the monopoly.

His prospects were now not only bright but steady. The discussion of his claim in parliament had drawn public attention, both to the mechanic and his production. And from the length of the term, the most ample outlay had every prospect of being repaid. But above all, his becoming a manufacturer of his apparatus was fortunate for his reputation. His first ideas were capable of great improvement. The chances of producing new and more perfect applications and combinations were all in his favour; every engine was an experiment which might lead to an improvement in the next production; and by this means the possibility of his claim to invention being appropriated by others, for mere technical perfection, was prevented.

The sale of the machine, as an article of trade, was conducted by Bolton, who showed himself in every way a master of commercial tactics. "And had Watt," says Playfair, "searched all Europe, he could not have found another man so calculated to introduce the invention to the public in a manner worthy of its importance." The public was invited to an inspection of the engine; the principles of its action were explained; its parts were described, and an estimate, both

mechanical and economical, was made of its powers.

But as, on this last head, something besides a manufacturer's assurance, was required to satisfy many who were to use and pay for the machines, a number of practical and scientific mechanics, whose personal and professional character placed their testimony beyond all suspicion, were invited to Soho, to witness a series of careful and rigid experiments made with the new engine; on the coals it consumed, on the work it performed, and on the time in which it did it. The results of these trials were compared with those of another series of experiments, made with equal care, in the presence of the same individuals, on Newcomen's engine, of the best construction, and in the best order. The superiority of the new engine, in every point, was thus shown to be immense. "And now," said the patentees, "all that we ask from those who choose to have our engine, *is the value of one-third* part of the coals which are *saved* by using our improved machine instead of the old. With our engine, it will not, in fact, cost you but a trifle more than half the money you now pay to do the same work, even with our third-part included; besides an immense saving of room, water, and expense of repairs. The machine itself which we supply, is rated at that price which would be charged by any *neutral manufacturer* of a similar article. And, to save all misunderstanding, to engines of certain sizes, certain prices are affixed."

To induce those who were either unable or unwilling to throw aside the expensive apparatus which they might have already in operation, Bolton and Watt took the old engines at a price

in many instances much beyond their value, in part payment for the new; and they even erected engines worth some thousands of pounds, on condition of being paid for them when they produced the estimated advantage. In other cases, the parts of the old engines were appropriated; and where this was practised, the alteration marked, in a striking and novel manner, the extraordinary value of the improvement. The *new clinder was placed within* the old working cylinder which served as a jacket, to prevent the radiation of heat; the inner, which now became the working cylinder, was seldom more than half the size of the outer one; but yet the power of the mechanism was greater.

To those, such as brewers, who still used horses, or those who calculated the effect of Newcomen's engine by that standard, a set of experiments were made, on the force which a horse exerts in moving certain descriptions of machinery; from a comparison of this, they said, by burning a certain quantity of coals, you will produce steam, which, used in our new engine, will do the same work as a horse. "Thus," Bolton said, "I will guarantee, with eighty-four pounds weight of Newcastle coal, to raise thirty millions of pounds weight one foot high; or the same quantity will grind eleven bushels of wheat; or it will slit and draw five hundred and sixty pounds weight of iron into nails. Therefore, by burning this quantity of coals, you will produce a power equal to that exerted by ten horses;" but in estimating this as equal to that number, his honourable mercantile spirit shone in a new and brighter light.

It was of infinite importance, that the power of the new mechanism should appear favourable, in a comparison with that of animals. And with this view, the lower the estimate of a horse-power,

the greater appeared the power of their engine. Smeaton, an engineer of unimpeached accuracy of statement and of great experience, had valued the force of a strong English horse as being equal to lifting a weight of 22,000 pounds one foot high in a day. But Watt and Bolton were not satisfied with this; they said that a horse could raise 33,000 pounds one foot high: thus stating the case against themselves almost to a *third* more: but they went still further; "one of our engines," they said, "are calculated so, that they will raise 44,000 pounds one foot high with a bushel of coals; and when we say our engines have the force of five, ten, or more horses, we mean, and guarantee, that they will lift 44,000 pounds for each horse power;" so that a machine which, according to Smeaton's estimate, would have a power of ten horses, Bolton and Watt only valued as exerting the power of five.

A mode of proceeding so fair and liberal was admirably calculated to set at rest all suspicion, and the public began, at length, to look with more complacency on the invention. But when Bolton had induced many to use the condensing engine, he wanted means to ascertain the work which the engines performed; disputes might arise from valuing the savings of fuel, where the data were to be furnished by those who were most interested in making them of small value; and an inspector over every engine, to have kept an account of the quantity of coals used and work done, would have been as expensive as it would have been an invidious and inconvenient method. Watt's invention was put in requisition to enable his colleague to keep his accounts with clearness and accuracy; so that, while the interests of the patentees were ascertained, it should be

done in such a manner as not to leave even a shadow of suspicion, or an opening to litigation. And the result was, Watts contriving a means of keeping an account of the work of the engine, for days or months, or years, without the trouble of reckoning, in so perfect and simple a mode, that at every period, after an hour's work or a month's work, the quantity of steam which had been used should be ascertained by a mere inspection.

This apparatus, which was called the *counter*, was formed of a series of small wheels, shut up in a box, having a dial and index-hand, to show how many revolutions had been made by the wheels. This apparatus was so placed, that every time the balanced lever rose, or descended, the wheels moved one tooth. It was sometimes attached to what was called the spring-beam floor, at other times it was attached to the lever beam. The box, which contained this mechanism, was shut by two locks, the key of one was kept by the proprietor of the engine, and the other key remained in the possession of Bolton and Watt. At certain periods, (every three months,) a confidential person in their employment visited the engines, and, in the presence of the proprietor, opened the box, and noted how many revolutions the wheel had made; from this it was easy to ascertain the quantity of coals that had been used; for, as this mechanism showed the number of times the piston had risen and fallen in the cylinder, that gave the number of times the cylinder had been filled with steam; and as it had been ascertained how much steam could be made from a bushel of coals, that gave the quantity of fuel that had been used in the Watt engine; and as the difference between the use of the new and old machine had been ascertained from the experiments, the third part

of the saving in quantity was valued by the prices of coals in the district in which the engine was placed, and this was the sum paid to Bolton and Watt for their permission to use the engine. At Chacewater Mine only, in Cornwall, the saving of coals was upwards of six thousand pounds a-year; and the patentees drew a revenue of two thousand pounds a-year from this alone.

The number of averages which might be inspected, satisfied even the most fastidious, and many excellent engines were soon erected in Staffordshire, Cornwall, Shropshire and Warwickshire. The prosperous course of affairs inspired a new ardour as the matter proceeded; and Watt continued to give still greater perfection to his exquisite mechanism, while Bolton's personal influence and frank habits made all feel the most perfect confidence in his representations and pledges; and so great was the "note of preparation," that upwards of forty-seven thousand pounds were spent by Bolton and Watt before they began to "touch the remuneration."

CHAPTER THIRTEENTH.

"I WILL VENTURE TO AFFIRM THAT HISTORY DOES NOT AFFORD AN INSTANCE OF SUCH RAPID IMPROVEMENT IN COMMERCE AND CIVILISATION, AS THAT WHICH WILL BE EFFECTED BY STEAM-VESSELS."—*Henry Bell.*

As long as Newcomen's engine was confined to pumping water, the common manner of attaching the steam piston-rod to the balanced lever by a chain was sufficient for its operation. But it had now become of great importance to use it as a first mover, in cases where the production of a continuous rotary movement was indispensable. To accomplish this it was often made to pump up water, which fell on a water-wheel, from which motion was communicated, as was also practised when using Savery's engine for the same purpose; but this, in many cases, was inconvenient, and, in all, expensive. Fitzgerald's rotary movement from the piston-rod directly, had been given up as impracticable; and a similar apparatus, which was applied by a Mr. John Stewart, and a Mr. Dugald Clarke, to some sugar-mills in Jamaica, had also been abandoned, from its being often out of order and requiring expensive repairs. Somewhat later (1768) an atmospheric engine had

been employed at Hartley Colliery, to draw coals from a pit, which had a toothed sector on the end of the working beam, working into a trundle, which, by means of two pinions with ratchet wheels, produced a rotative motion in the same direction by both the ascending and descending stroke of the piston; and by shifting the ratchets the motion could be reversed at pleasure. This engine had *no fly-wheel,* and went sluggishly and irregularly.

Its application, however, to move boats, which was among the earliest projects to which its use had been suggested after its invention, was again proposed by M. J. A. Genevois, a minister in the Canton of Berne, who in 1759 published, at Geneva, a book describing his discovery of what he called the "great principle," and which appeared to him of such importance to the English nation in particular, that he came to London in 1760 to lay his book and his plan before the Commissioners of the Navy. These gentlemen having desired him to furnish them with extracts of those parts of his book which related to navigation; the simple Bernese not only made the extracts, but had them translated and printed.

"He found," he said, "common oars had ten essential faults, but principally because the supreme geometrician had not given a pattern of these in any living creature, he thought was a strong objection to the goodness of the method of propelling a boat by the usual means. The patterns of oars which nature gives us are the tails of fish, or the feet of swans, or ducks, and the imitation of the web-foot is the easiest and most practicable." "It is notorious," he continues, "that the duck bends its feet in bringing them forwards, and the membranes are so closed as almost

no longer to resist the water:" this mechanism being absolutely free from the ten objections in his oar, he joined together the two qualities in the pattern, its swiftness and its non-resistance in the return by making oars with a joint at the feather, which expanded so as to be quite flat when opposed to the water in acting, to impel the boat forwards; and to fold almost together, and oppose no resistance to the water when they were withdrawing from it;—like a duck's foot, closing as it comes forward, and opening as it is drawn back *.

His "great principle," which was to consider "springs as a magazine or repository of all the powers which are lodged in them, and to make them restore with violence, or with weight and measure, any power bestowed on them," he applied as the intermediate means of moving his natural oar. To bend the springs, he describes a sort of

* We quote the following anecdote from his pamphlet. "It is true, an honourable gentleman, one of the members of the Navy Board, told me, when I appeared before them in August, 1764, that, about thirty years ago, a Scotchman proposed to make a ship sail with gunpowder; but having found by the experiments made for that purpose, that thirty barrels of gunpowder had scarce forwarded the ship the space of ten miles, this invention had been rejected. To this I answered, that he acquainted me with a thing quite new to me; that his scheme was deservedly rejected, but that my work was of another kind. I have since been told, that it was by the retrogradation of one or more cannons on the poop, this man had conceived the hope of forwarding a ship. This put me in mind of the trial a celebrated gentleman made, many years ago, to set a boat going on the Rhine, by the effusion of the water from a tub on the stern, by a hole towards the prow; this was only as short. As for the Scotchman's work, one may easily see it has nothing in common with mine, but the thought of gunpowder."—*Inquiries tending to the Improvements of Navigation*, p. 20. London, 1760.

cannon with a piston, in which he ignites gunpowder: but Genevois is here noticed as proposing to bend his springs, which move his oars, by Newcomen's engine. Before, however, he submitted his plan to the Commissioners, he had their pledge that they would warrant to him the merit of the invention; "but I desire all equitable persons to believe, that I had some reason to act in this manner, drawn from considerations more honest and suitable to the character I have the honour to be invested with, than the mean views of a contemptible vanity. I durst flatter myself," says the worthy pastor, "that discoveries so useful to mankind in general, might be so to my family."

But this scheme, which had been proposed by many, and attempted unsuccessfully by three experimenters, was now to have a fair trial. The Comte d'Auxiron*, who had already appeared before the public with advantage, succeeded, in 1774, in bringing a scheme for moving boats by a steam-engine, before a number of individuals who associated for the purpose of enabling the Marquis to carry his plan into execution. The experiment was tried on the Seine, near Paris; but the engine, by which the wheels were propelled, not

* The COMTE D'AUXIRON was a native of Basançon, and a member of a family, whose father and brothers devoted to the sciences, adorned their favourite studies with some estimable performances. He was born in 1728, and entered the army at an early age, in which he held the rank of a captain of artillery; the duties of his profession interfering with his tastes, he solicited his dismission, and retired in 1765. In the same year, he published a proposal for supplying Paris with water, and continued afterwards to publish occasionally treatises on philosophical subjects. In 1769 he printed a Theory of Rivers, and means for preventing the ravages of Floods, a work evincing much observation. He died at Paris in 1778.

having the necessary force, the boat moved so slowly and irregularly, that the company, at whose expense the trial had been made, considered the result offered no inducement to persevere; and judging from what they had seen, navigation by steam, in their opinion, could not supersede, either on the score of speed or economy, the ordinary method of towing by horses.

Perier, the elder*, since well known in France as an able and accomplished mechanic, assisted at this experiment; and, notwithstanding the discouraging opinion, formed by many of his friends

* Jacques Constantin Perier, a Member of the French Academy of Sciences, was a native of Landes, and the eldest of three brothers who were bred millwrights. His second brother Augustus Charles, was his colleague during his whole life. The third brother died when a very young man. The centrifugal pump, which they constructed as their first essay, was placed in the gallery of mechanical models, formed by the Duc d'Orleans, and for its merit is yet preserved in the Conservatoire des Arts et Metiers, at Paris. Jacques Constantin, that he might acquire more profoundly the elements of his art, made journeys to England. The year he returned from his first visit, he was employed by the government to erect engines on the Isle de Cignes to supply the place of the water-wheels, which had been stopped by a rigorous winter; when the urgency had passed, the millers left the machines to their fate. During the early part of the revolution, the Periers cast cannon and other warlike stores for the state. But the fall of the assignats, with which they had been paid, almost crushed them. And the government, as if to consummate their ruin, refused to listen to their claims for compensation. In these times, they employed their workmen in fabricating engines in general demand by manufacturers. The manufactory, which still flourishes, and ranks as the first in point of excellence and extent in France, has produced a great number of steam-engines, which have been erected in all parts of the continent, and are esteemed for their excellent workmanship. Jacques Constantin also established the foundery at Liege for casting cannon. He died at Paris, in 1818, in the 76th year of his age. He was the author of a small treatise on steam-engines.

from the Marquis's failure, he repeated the trial, with some improvements in the mechanism, in the following year. The steam-engine he used was an imperfect model which had been laying about his workshop, of a power about equal to that of one horse. This was placed in a boat, and attached to two wheels, one at each side, with a contrivance to give them a rotary motion. The performance of the model was as defective as that used by d'Auxiron, and the boat moved but slowly against the current of the Seine. This trial not being so favourable as Perier had anticipated, he did not proceed further with his experiments; as the project did not now appear to offer any temptations for him to go on with it, in preference to some others, to which he had devoted his time, and in which he had embarked his capital.

The Marquis Ducrest, who was present at Perier's exhibition, gives a good account of it; but his impression was decidedly in favour of its being easily practicable to move boats by a steam-engine; he explains, in a very satisfactory manner, why that no inference ought to be drawn, as to the speed of vessels navigated in this manner from this experiment, because it was not fairly made. For, instead of a boat of this size being propelled by an engine, having a power only of one horse, it ought, according to his calculation, to have been furnished with one having the power of four or five horses to have driven the wherry against the stream of the Seine, with so small a velocity even as that of the towed boats, or from three and a half to four miles an hour*. Fortified by this opinion,

* *Essais sur les Machines Hydrauliques*, p. 184. Paris, 1777.

Perier did not altogether abandon the subject, and in succeeding years he made a few attempts in substituting other mechanism for that of the paddle-wheels, which he thought were defective substitutes for oars, and which in his view occasioned his failure. But he was too languid in the pursuit to accomplish so great a matter: his attempts do not appear to have excited much attention in France, and no traces appear of their having been noticed in England.

It was two years after his first experiment with his steam-boat, that Perier formed a company for supplying the city of Paris with water. In his own manufactory, which at that time ranked as the first in France, he made steam-engines; yet with an honourable acknowledgment of the superiority of those manufactured by their great inventor, he came to England, and succeeded in inducing Bolton and Watt to sell him an engine on their best construction, and with all their latest improvements. He remained at Birmingham during its fabrication, and procuring a license from the English government for its exportation, he carried it to Paris, and by the assistance of two skilful mechanics, who accompanied him from Soho, and the instructions he had received from Bolton and Watt, he erected it at Chaillot. This is the engine described by Prony, in his splendid book on the Steam-Engine, who is minute even to prolixity in describing its parts; but omitting to state to whose talents the beautiful mechanism was due, he encouraged the inference that Perier was its inventor, as well as its fabricator. Yet Prony, who ranked as one of the most liberal and the most accomplished scientific men of his time, happened to be that individual, under whose immediate direction Perier was despatched to England, who

was in correspondence with him while he was attending the workshops at Soho, and who actually superintended Perier when he put the parts together at Chaillot*.

The Water-Company was a still more unfortunate experiment than the steam-boat. A great outcry was raised by a party at Paris against its projectors, and notwithstanding the literary exertions, in its favour, of the celebrated Beaumarchis, who had ventured some of his property in the speculation, it was completely borne down by its opponents, who were led on and stimulated by "the ferocious and frantic declamations of the renowned orator, Mirabeau."

The prodigious stride made by Watt in his condensing engine, soon began to stir up attempts to improve the rival mechanism. The most ingenious was displayed by Doctor Falck, who, in 1779, described a method of doubling the effect of the steam, by making use of its expansion. He used two cylinders, each fitted with a piston, and steam was admitted into each by a common regulator; but when it was flowing into one, it was prevented from having access to the other; and the steam was made, after it had depressed the piston into one cylinder, to flow into the other, and act on its piston in the same manner. By means of a wheel fixed into an arbour, the piston rods were kept in a continual ascending and descending motion, in the same manner as the rods of a common air-pump, by which they move a common axle. With the same quantity of fuel, Falck estimated he could produce a double effect,

* This engine was at work in 1814, but Farey observes it was not a good specimen of Watt's abilities, that is, in comparison with what he produced twenty or thirty years afterwards.

but it does not appear he made any experiments with a model. His idea seems, however, to have been acted upon, for Mr. Farey has stated that he saw an engine on Newcomen's principle, working on this arrangement.

It may here be observed, that, before this period, Watt, who had noticed the effect of the expansion of steam when admitted into a vacuum, had availed himself of this knowledge, to equalize the motion of the piston in its descent, by shutting off the steam from the cylinder before the piston had reached the limit of its stroke. It is not, however, likely that Falck was acquainted with this method, which might have been practised in the condensing engine, without attracting even the observation of one minutely examining its construction. In fact, this refinement appears to have been quite unknown to mechanics, until the appearance of Falck's pamphlet.

CHAPTER FOURTEENTH.

"THE MORE IDLE A TINKER, THE MORE CONCEITED HE IS OF HIS SKILL; AND THE GREATER IS THE DANGER THAT IN STOPPING ONE HOLE IN YOUR KETTLE, HE OPENS TWO."—*Swift.*

THE great practice Smeaton had in planning machinery on a grand scale, was amply merited by the pains he took to become master of the knowledge of every circumstance which could affect its action or power. After his judgment had become matured by experience, he placed little if any dependence on theory; but became a diligent collector of facts regarding the peculiarities, proportions, and effect of machines which had been erected by others. This gave a consistency and precision to his opinions and practice, that we look for in vain in the works of his cotemporaries; they do not appear to have felt that the routine of their practice might be corrected, by observing even the mistakes of others, or they were too idle to look beyond their own Gotham for improvement.

It is on account of this well-directed industry, that his labours are yet esteemed as standards of construction, and of well understood and effective

combination. And the most flattering testimony that could have been borne to the success of his deviation from the beaten tract to improve the steam-engine, is furnished by Watt. When speaking to him about the terms upon which he granted permission to use the condensing engine, "We charge," says he, "our profits, in proportion to the saving of fuel made in our engines, when compared with a common one, which burns the same kind of coals. We ask a third part of these savings, but in all these comparisons, our own interest makes us except your improved engines, unless we were allowed a greater proportion of the savings."

The value of these improvements will be best understood from experiments he made in 1769. At that period fifty-seven engines were in operation at Newcastle, having a total area of piston, equal to 116,485 square inches, and operating with a power equal to that which could be exerted by 1,188 horses.

Fifteen of these machines were selected, as being a fair specimen in every case of the whole number, having an energy equal to that of 376·5 horses. The total superficial area of their pistons was 36,899 square inches, having an average pressure of 6·72 pounds on each inch of piston, which moved at a speed of 100·2 feet per minute, and raised a weight of 5·6 millions of pounds to a height of one foot, with eighty-four pounds weight of Newcastle coal.

So small an effect, with so great an expenditure of fuel, appeared to Smeaton to arise from incorrect proportions given to the various parts of which the mechanism was composed. The boilers, he imagined, were too small to generate the proper quantity of steam, and this defect was aggravated

by an improper formation of their fire-places. The management of the fire too was little understood, and carelessly attended to. The pipe conducting the steam to the cylinder, had not sufficient capacity to allow it to flow into the cylinder with the proper velocity. The injection cistern was placed too low; the water laying on the piston, abstracted the heat from an immense quantity of vapour. The cylinder itself was faulty in proportion, and very defective in its execution. Every thing appeared as if it had been placed in its position by chance, and proportioned in the same manner; but as often as one machine was found better than another in one part, this was neutralized by its more glaring faults in another part, so that with so great a latitude, no one had had the good fortune for his guessings to have been the right one.

Yet, although the greater number of these defects were so obvious, and of such magnitude, that the removal of even one of them would have added greatly to the power of the apparatus, they were totally overlooked by the fabricators of the mechanism. If they found a deficiency of power, they increased the area of the piston, estimating the effect by the weight placed upon it, without reference to the velocity with which it moved, or to the quantity of coal which was consumed to produce it.

Smeaton soon found that the attempt to get the information he desired, from trials upon engines in operation, was beset with very great difficulties; no estate could have survived the expense of making a series of experiments, where each would absorb a moderate fortune. He took the next best plan, and erected a small engine at his house at Austhorpe; with this during four years he made a great number of experiments, on every point

which he thought might affect the action of the atmospheric engine. By mere attention to keeping a thin clear fire evenly spread over the grate, he saved a sixth part of the heat with a more regular performance. An increase of effect was also produced by admitting air under the piston during the returning stroke, or when the counterweight was drawing up the piston. He minutely examined the action and effect of the injection, and found that, by apportioning it, he could regulate the motion of the piston; he saw that there was a loss of power from regulating the motion of the engine by a *cataract*. He also ascertained the quantity of water evaporated by a given weight of fuel; he defined the best proportion of the surface of boiler, that should be submitted to the action of the fire to generate a given quantity of vapour. He pointed out the proportion of vapour that was condensed in merely heating the cylinder and piston, without producing any useful effect besides that, and overcoming friction, and the best velocity with which the piston should move, and the load it should carry. He made some minor improvements in the material of which the under side of the piston was formed, the construction of the jet orifice, the framing of the great lever, the arrangement and construction of the hand-gear, and in the framing and proportions of the parts throughout.

The first opportunity he had of carrying his ideas into practice, was at a coal mine near Newcastle. The engine he was called upon to improve, had a cylinder fifty-two inches in diameter, which, when loaded with 8·92 pounds on each square inch, and moving at the rate of 51·25 feet each minute, raised 4·82 millions of pounds' weight one foot high, with an expenditure of eighty-four pounds' weight of Newcastle coal.

In the new arrangement, Smeaton retained the old cylinder and pump-work; he made the piston move through eighty-four feet in a minute, with a weight of 7·5 pounds on each inch, and he thus raised 9·45 millions of pounds one foot high, by the same weight of coals which could only raise about half the weight in the machine which had been superseded. This increase of effect was independent of friction and other resistances; but as there was a weight of upwards of twenty-seven tons poised on the axis of the lever during the falling of the piston, and about 9¾ tons during its returning stroke, taking the loss of effect from moving this enormous weight into account, the eighty-four pounds of coal may be estimated to have raised eleven millions of pounds one foot high, and that too with a much greater uniformity of action than was produced in the old engine.

The general form of the details of the engines which were designed by Smeaton, is shown in the engraving. The engine for which these were constructed was erected at the Chacewater mine, in Cornwall, and was accounted at the time one of the most powerful machines which had been used in England. Its cylinder was 72 inches in diameter; the piston had a 9½ feet stroke; the water was drawn at three lifts from a depth of 50 fathoms, and the weight of it in the pumps was upwards of 14 tons. The working beam was 6 feet 2 inches in depth, and composed of 20 fir beams, united together by massive hoops of iron. Three boilers were attached to this huge apparatus; one of these was placed as shown in the engraving, the other two were placed in the outside of the engine-house, each in its separate building.

In the engraving marked SMEATON, Fig. 1, is an elevation of the self-regulating apparatus, or hand-gear. Fig. 2, is a plan, or horizontal section, of the same mechanism. Fig. 3, a section of the sliding valve, through which the steam was admitted from the boiler into the cylinder. Fig. 4, section of the bottom of the cylinder. In all the figures the same letter is placed on the same part. *a*, is a part of the cylinder; *d*, a part of the plug-frame; *e*, injection water-pipe; *f*, pipe conveying steam from the boiler into the cylinder, and at the bottom of which the valve shewn in Fig. 3, is placed; *i*, injection cock; *k*, forked lever which opens and shuts it; *l*, another forked lever for opening the sliding valve on the steam-pipe, which is marked *o*; *m*, a catch communicating with the cataract; *r*, tumbling bob of the injection cock; *t*, tumbling bob of the steam-pipe valve. These weights perform the same office in this apparatus that they have already been described to perform in Newcomen's early engines.

The operation of this machine is nearly the same with others which have been already described. In the figures the parts are in the position they would occupy if the piston were at the top of the cylinder, (which is filled with steam,) and the steam and injection cocks were shut, and the apparatus ready to act as soon as the cup of the cataract is filled with water. At the instant this is accomplished it falls to one side, and makes the bent lever 5 draw up the chain *s* of the catch *m*, and the prong *x* being disengaged, the weight or tumbling bob *r* impels the prong 1 on the lever 2, and during its movement into the opposite position opens the injection cock *i*. The jet condenses the steam beneath the piston, which falls

ing into the cylinder, performs its working stroke; at the same time the tappet-frame *d* descends, and when near the termination of its motion, a pin 6, striking on the arm *y*, opens the steam valve, and at the same instant another tappet shuts the injection cock; the counterpoise now draws the piston to the top of the cylinder, and when it is about to reach the limit of its returning stroke another pin in the plug frame moves the *y* piece, and the steam valve is again shut. The cylinder is now filled with steam, and remains so until the cataract cup inclines to one side, when the fall of the tumbling-bob *r* again opens the injection cock and the piston descends as before.

There were also several extraneous circumstances which produced irregularity in the mechanism, even when the steam power was made to act with great uniformity. In all the machines which have been described, the weight of water, or other load which the engine had to raise, has been considered to be equal and constant. But in the greater number of instances in which steam power was employed, the water which had to be drawn from a mine, did not accumulate with regularity. The operation itself of pumping the water which had accumulated, varied the load on the pumps; and when, from any cause, the water suddenly fell in the cistern, and air found its way under the pump-barrel, if the piston were working with its usual load, its descent destroyed the apparatus. The general rate of the motion of the piston, might be perfectly regular, and from time to time be regulated by decreasing the load on the piston, by making a less perfect vacuum, or by admitting more or less water into the cylinder; but this required so much care on the part of the attendants, and such

disastrous consequences ensued when it was omitted, that it was rarely resorted to; an obvious and simple, but not very economical method was preferred. Where the situation permitted, the water was allowed to accumulate beneath to a certain extent, and the engine was then put in operation to pump a certain portion of it to the surface; it then ceased working until a second accumulation had taken place, and so on constantly.

A better method was to keep the machinery always in action, and to regulate the engine so that it should make only a certain number of strokes in a minute, and thus allow time for a fresh accumulation between each stroke. The *cataract*, a well known contrivance for this purpose, was used by Smeaton, and also in many cases by Watt.

A small pipe, *a*, which proceeds from a cistern *c*, is furnished with a cock, *d*, to regulate the size of the stream of water which falls from it into a funnel, *e*; this funnel is placed over a cup fixed on the end of a bent lever, *f*, *g*, that moves on an axis, *h*; a chain or wire, *i*, is fixed to one end of this lever, the other end of the wire is attached to a spanner or catch, which acts by its rise or fall to engage or disengage a lever that opens the cock of the injection-pipe. The cup and bent lever are placed in a box, through the bottom of which the chain proceeds; a small pipe, *k*, carries off any water that may fall on the bottom. It is first found from trial, how often a certain stream will fill the cup the required number of times each minute, and the cock is adjusted accordingly. The water then which falls into the funnel, is guided into the small cup, and when it is filled, the weight of the water makes it fall over, and turns the opposite end of the bent

lever on its axis, and the chain fixed to it raises the end of the catch, which acts to open the injection valve; and this condensing the steam, the engine makes a stroke, and the counterweight lifts the piston into its former position, as has already been described in the Chacewater engine.

During this operation, the water from the cup is emptied into the box and carried off by the pipe, and the chain, acting as a counterweight, quickly restores it to its position under the funnel, and the stream of water filling the cup again, it a second time falls to one side, the engine makes another stroke, and so on successively. It is obvious, that as the stream of water is made more or less, a greater or less time will be required to fill the cup, and of course a greater or less number of times will the injection cock be opened, and the piston make its stroke.

Another plan practised by the old engineers, was still retained in many situations, to ascertain the depth of water in the pit, in order to guide the engine-keeper to regulate the movement of the machine, and to avoid the accident of water failing in the pump, when working with its usual load.

An iron pipe, perforated with holes at its bottom, was placed in the cistern of the mine; a wooden cylinder (having a projecting piece of iron fastened to its under side) made smaller than the diameter of the pipe, so as to move easily up and down, floated on the surface of the water in the pipe. A cord was attached to this float which passed through a hole in the cover of the pipe, and was carried up the pit shaft and guided over a pulley into the engine-house, where it passed over a second pulley, and was terminated by a small weight, hung within reach of the en-

gine-keeper. By pulling this cord, he could always tell whether the water stood high in the cylinder, or was nearly exhausted. In the first case the float was buoyant, and in the other, when the float was raised by the rope it fell, and the piece of iron coming strongly in contact with the iron bottom of the pipe, gave the information that was desired; and by a little practice, he could also distinguish whether the float was nearly at the top of the pipe, which it would be, when the cistern was filled with water. Watt sometimes used this contrivance with a modification, which better adapted it to his practice, and he made it regulate the working of the engine. Instead of a rope, a strong wire was attached to the float, and this was connected to the lever which opened and shut the injection cock and the passage for steam into the cylinder. The fall of the float was made to diminish the opening for the steam, and its rise to open the valve; and in some instances, it was also made to regulate the cock of the cataract-pipe, so as to allow a greater quantity of water to escape into the cup when the float rose, and thus by filling it oftener, increase the number of strokes made by the steam-piston. The fall of the float to the very bottom of the pipe, either shut the steam-passage or the cataract cock, and thus the accidents which would have befallen the apparatus from a failure of water in the pumps were prevented, as the motion of the engine ceased entirely.

It is probable Smeaton was also the author of the *warning-gauge;* for it first appeared in engines which he constructed, and he made it serve as well for a gauge and feeding-pipe. A pipe inserted through the roof of the boiler, was

carried down to the lowest level at which the water should stand in it. Three inches above the lower termination, was a hole half an inch in diameter; and three inches above that, a number of small holes were also pierced, at the height at which gauge cocks were usually placed. When the water sank beneath the level of the upper holes, the steam issued up the pipe, and by its hissing noise gave warning to the engine-keeper; if, however, this was not attended to, and the water was allowed to sink still lower, the steam issued with violence through the half-inch hole, which produced a sound much stronger than that which had proceeded from the holes above. Should these two warnings have been insufficient to call the attendant to his duty, as the water subsided still nearer to the bottom of the pipe, the steam of course increasing in its elasticity, issued along with the water with a violence that warned the careless servant of the danger, even should he have been at a distance from the boiler.

Smeaton, and he was also followed by Watt, had another small pipe inserted into the water in the boiler, to a certain depth. When the water was evaporated to the level of the lower orifice of the pipe, the steam escaping from it made a whistling noise as it passed through a whistle mouth-piece fixed at the upper extremity. This gave so audible an intimation, "that even a large parish might be summoned by its sound, to rouse the engine-keeper from his slumber, or to expostulate with him on his neglect of duty." The contrivance is an excellent one, and should find a place on all boilers on every construction.

In many of his early engines, Watt also adapted another gauge to the boiler, to mark the height

of the water in it from inspection. A small vertical glass tube was cemented to two copper pipes, one at each end of the glass tube. One of the copper pipes is placed in the water in the boiler, and comes to the outside, where it is joined to the glass tube; the other open end of the copper pipe is returned into the boiler, above the level of the water. The glass part of the tube is thus on the outside of the boiler; and as one extremity of the tube is immersed in the water, and the other rises in the steam, the water stands in the glass tube at the same height that it does in the boiler, and its height is ascertained by a mere inspection: this tube was usually placed over the fire-door or near it, so as always to be in sight of the engine-keeper. But in this situation, being liable to accidents, the tube was often broken, and its use was on this account discontinued.

In a very early stage of his career, Smeaton began to use a cheaper material for many parts of his machines than his cotemporaries did. In the greater number of the earlier engines erected by Newcomen, and his successors, brass was used for the cylinders, and pump barrels, and valves. This expensive substance was probably employed from the greater ease with which vessels formed of it could be bored and turned true and smooth. Still this facility appears to have been confined within very narrow limits, for it was considered to be a difficult matter to cast and bore cylinders of a diameter not exceeding thirty inches, and about one-third of an inch in thickness. Another substance, of which the composition is now unknown, but called at the time *spelter*, or brass solder, was first applied successfully by Mr. Ford of Colebrook Dale, as a material for steam-cylinders. It is described as having run easier,

and having been cast as true as brass, and bored full as well or better, when it had been warmed a little. When cold, it was as brittle as glass, but the warmth of a hand soon made it so pliant, that a shaving of it could be wrapped round the finger like paper; the metal never rusted, and, therefore, worked better than iron.

The methods by which these cylinders were fashioned, or what description of artisans undertook the employment, is not now known. But it has been conjectured that the bell-founders may have occasionally acted as brass-founders. Their productions, however, were faulty in workmanship, and of great expense. The brass cylinder of an engine erected in Scotland, in 1727, (and which was made somewhere beyond London) cost nearly two hundred and fifty pounds sterling, and the total value of the apparatus of which it formed a part, was upwards of one thousand two hundred pounds, exclusive of the expense of the labour of putting the pieces together, and of the erection of the building in which it stood. An engine on the same principle, with nearly the same details, but with a cylinder more than a third larger, is estimated by Smeaton not to exceed seven hundred and fifty pounds; this smaller sum includes pipes made of iron, instead of elm pump-trees bound with hoops, which were used in the Scottish engine.

This great difference in the cost of the machines did not altogether arise from the intrinsic value of the substances which were used in their formation. But part of it was produced from an improvement which had recently been made in the manufacture of the cheaper material, by which its softness and cohesion were so much increased, that it became a substance estimable for its plastic qualities, and for its durability.

Heretofore, in consequence of its brittleness and unsound texture, as much as its extreme hardness, cast iron had never been used for parts which had great strains to bear, and cannon-balls, ballast for ships, iron-rail-fences, furnace bars, backs and hearths of fire-places, and small boilers, were nearly all the articles which were usually made of it; and, excepting the first, its use was still very limited, even in the other cases enumerated.

After the method of using mineral instead of vegetable charcoal in its manufacture was adopted, its cheapness was also in favour of its becoming a substitute in many cases in which brass or copper were considered as more appropriate; particularly in place of brass, for the cylinders and pumps of steam-engines. Desaguliers, so early as 1743, mentions cylinders of cast-iron, which, he says, could be made to have a good form and polish; although he dissuades from their being used, on account of their possessing the very property which Smeaton found was greatly in their favour; their not cooling so rapidly as the brazen vessels. But until the time we have mentioned, it is doubtful if they had become known in practice.

Smeaton appears among the earliest, if he were not actually the first who began to use it extensively as a substitute, not only for brass, but hammered iron. He made the first great axis of a windmill with cast iron in 1751, and afterwards continued the practice, although with no great success on the score of durability, until he got his castings from Carron; and it was in 1769, that he made the first axis for a water-wheel at this establishment. Afterwards he used it on all occasions, for cog-wheels, and shafts of all dimensions, and in framing generally, where he was at perfect liberty to follow his judgment in the selection of materials.

Although the small cast-iron boilers which had been long used by brewers and dyers were found durable, they were, nevertheless, considered to be more expensive than *thin* copper or plate-iron boilers; and their thickness was given as a reason for their requiring more fuel * than the others. These boilers were, however, open at top; those for steam-engines required to be enclosed in a manner so as to retain steam of considerable elasticity. Plate-iron was long used for the parts exposed to the action of the fire, and the dome was made of lead by the plumbers, as it was thought iron rivet-joints could not be made so tight as to retain the vapour. Afterwards the practice was to form the roof of the boiler with cast-iron plates, cast in segments, which were joined together by bolts passing through flanches projecting from the edge of each segment, and the joints between the flanges were tightened, by driving in wooden wedges from the outside; by this means, if one plate failed, it could be removed without deranging the others. Smeaton, in almost every instance, had formed his boilers of hammered and moulded iron, but latterly he gave some gigantic specimens of boilers built solely of cast-iron; each of the three which

* Some attempts had been made to economise the heat which was lost in manufacturing copper from its ore, by making the vapour which escaped from the smelting furnace, pass under the bottom of the boiler of the steam-engine. At Camborne copper-mine, the boiler was built of moorstone (or granite) and jointed with a cement made of Aberthaw lime, which hardens under water. The smoke which was to heat the water was conducted through it in copper tubes, passing from end to end. The boiler was twenty feet long, nine feet wide, eight feet and a-half deep; the three copper smoke tubes were twenty inches each in diameter; two of them were placed parallel to the side of the boiler within seven inches of its bottom, and the third in the space over them; the flame passed through one into the other and rose into the third, from which it was conveyed into the chimney. On trial it failed.—*Nicholson's Journal*, vol. viii. p. 169.

he constructed to supply steam to the engine for draining the docks at Cronstadt, weighed upwards of fifteen and a half tons.

The increasing demand for the ponderous machinery of steam-engines having led capitalists to the erection of numerous foundries in different parts of the kingdom, their emulation was greatly instrumental in improving the art of casting and finishing cast-iron ware. Carron, the first establishment in regard to magnitude, continued also to be the most celebrated for the general excellence of its productions; and it more especially enjoyed a great reputation for the truth with which its cylinders and pump-barrels were bored and polished. The method usually followed was that employed from time immemorial for boring the wooden pipes or pump trees, used to convey water. The pipe, placed in a carriage, was made to move forward as accurately as could be in the direction of its axis, and to press against the face of the borer; this was a tool constructed of several cutters firmly fixed in a solid wheel, which was made to revolve by the power of horses or a waterfall; and as the cutter excavated the centre of the pipe, the frame moved forward so as to keep the tree pressed against the tool.

But notwithstanding the proportions and modifications which Smeaton introduced into the boring-engine he designed for Carron, and which gave the superiority to the cylinders and pump-barrels fabricated in this foundry, over those sent from rival establishments, still the form of the cylinder, when drawn from the mould, influenced more or less that which it could receive from the action of the borer.

Much of the advantage which now began to be experienced by engineers, from a greater atten-

tion paid to the mode of finishing pipes and cylinders, would have, in truth, been greatly circumscribed in their importance, but for an invention of Mr. John Wilkinson, the proprietor of iron works at Bersham near Chester. In this beautiful contrivance, provided there was a sufficient thickness of metal, the want of truth in the casting of a hollow vessel was quite immaterial; for Wilkinson made his borer advance into the cylinder *along an inflexible rod*, which was fashioned with the greatest possible truth. So that the tool must excavate in a line as true as that which was formed by the rod which guided it; and this, without question, was one of the most important improvements which had been introduced into the machinery for the manufacture of machines. Indeed, so universal was its application, that it may be considered as forming an era in their manufacture, as having laid the foundation of all the wonders which have since been achieved, in giving the utmost accuracy and beauty to implements and machines of every kind, and of every variety of construction.

But in nothing was its importance more clearly seen, than in the fabrication of the parts of steam-engines. Cylinders of five and six feet in diameter, and piston rods of corresponding sizes, could be formed by its agency with the greatest truth, and as much precision as before its introduction it was possible to give to the small cylinders of air-pumps.

Watt speedily availed himself of his friend's improvement; and by having his rods and pumps properly bored and polished, he may be said now, for the first time, to have had it in his power to give comparative perfection to his own invention. For even the excellent workmanship of the Carron cylinders was so much surpassed by those

made at Bersham, that when a new engine, on the condensing principle, was to be erected at Carron itself, Bolton writes to the chief of the establishment, that he must either change his mode of boring cylinders, or get one bored by Wilkinson, "for he has," says he, "lately bored us some nearly without error; one which we have put up at Tipton, fifty inches in diameter, does not err the thickness of an old shilling in any part;" and in a letter from Watt to Smeaton, he says, "so great has been the improvement made by Wilkinson, that he can promise upon a cylinder, having a diameter of seventy-two inches, not being further distant from absolute truth in the worst part than a *thin* sixpence." But even this deviation (about the fortieth of an inch) was greater than could be found in these ponderous vessels; for from the admirable nature of the process, it was next to impossible that so great an error could be produced in a vessel, of however large dimension.

CHAPTER FIFTEENTH.

"EVERY IMPROVEMENT IN A STAPLE MANUFACTURE WHICH LEADS TO ITS EXTENSION, ALTERS THE POSITION OF A COMMUNITY OR A NATION WITH REGARD TO EVERY THING WITHIN AND AROUND IT."—*Pitt.*

THAT portion of the wonderful Soho which had been assigned to Watt for the manufacture of his exquisite mechanism, was soon found to be of incompetent dimension for the developement of the magnificent scheme which Bolton had formed, to become the sole fabricator of the condensing engine in England. A neighbouring spot was, therefore, selected, in which might be concentrated those artisans and machines that were found to be necessary for the formation of every part of the apparatus. "We are systematizing the business of engine making," says Bolton to Smeaton, "we are training workmen, and making tools and machines to form the different parts with more accuracy, and at a cheaper rate than can possibly be done by the ordinary methods of working. Our workshops will be of sufficient extent to execute all the engines which are likely to be soon wanted in this country; and it will not be worth the expense for anyother engineers to erect

similar works, for that will be like building a mill to grind a bushel of corn." The classification of labour answered his most sanguine expectation. A band of workmen and artificers, expert in the management, and familiar with the construction of the machines. was soon trained; and to every engine which Bolton erected, one of these artisans was attached, until the servants of the proprietors could be instructed in its management. And Soho became a nursery, from which engineers were sent forth to carry its improvements into every part of the country; and Bolton was soon enabled also to state, "that comparing the new engines with the old, (those not of the same size but of the same power) the first cost of both was nearly the same." But in every point relating to elegant and accurate workmanship, the comparison was immensely in favour of the Soho machines.

A philosophical friend of Watt's had given currency to the statement, that his condenser was originally suggested as an economical appendage to Newcomen's engine; but he himself contradicted the statement. "From the first," he said, "I intended to operate with steam instead of the atmosphere, and my apparatus was so constructed."

This modification it was thought, if made on Newcomen's engine, would improve it at a very small additional cost; and the proprietors of some large and expensive machines on that peculiar construction, being anxious that the condenser should be adapted to their apparatus,—with this view Watt was persuaded to make an experiment on an engine at Soho; but the results, he tells Smeaton, "were not such as to induce him to try it any where else." He refused, there-

fore, to apply it to the engine at a large mine in Cornwall, because the savings of fuel were not great, in comparison to the complete machine. "By adding," says he, "our condenser to engines that were not in good order, our engine would have been introduced into Cornwall, which we look upon as our richest mine, in an unfavourable view; and without such profits as would have been satisfactory to us or to the adventurers, and thus have injured our reputation."

The condenser in its first form, was composed of several thin coppper-plate pipes communicating with each other, and placed in a cistern kept constantly filled with cold water. Sometimes, instead of pipes, thin flat copper vessels were employed, and placed so as to present the greatest possible surface to the action of the cold water in which they were immersed. The steam which flowed from the cylinder into the vessels or tubes, coming into contact with the cold metallic surfaces, was condensed with great rapidity. But a very few trials showed that an extent of condensing surface, necessary to produce a perfect vacuum under the piston of a powerful engine, could only be attained by using tubular or flat vessels, altogether of preposterous magnitude.

The water also in which these condensers were often placed, formed a crust upon their surfaces which greatly diminished the power of the metal for conducting heat; and this impaired its efficacy as a medium for condensing vapour. Notwithstanding this drawback, the method was considered to be an economical one; for the air and water produced by the condensation could be extracted by a pump of a size that would require a comparatively moderate power to work it.

In the end, the inconvenience of large vessels decided Watt to sacrifice a little more power than he before thought was advisable, in order to have a less cumbrous mechanism; and he returned to a discarded scheme that he had tried in the Kinneil engine, of condensing the steam by bringing it into contact with a jet of cold water, as it flowed through the eduction pipe into the cylinder. "In pursuing this idea," says Watt, "I have tried several kinds, and have at last come to one, which I am not inclined to alter. It consists of a jackhead pump, shut at the bottom with a common clack bucket, and a valve in the corner of the pump to discharge the air and water. The eduction steam-pipe which comes from the cylinder, communicates with this pump, both above and below the bucket, and has valves to prevent any thing going back from the pump to the eduction pipe. The bucket descends by its own weight, and is raised by the engine, when the great piston descends, being hung to the outer end of the great lever. The injection is made both into the upper part of this pump and into the eduction pipe, and operates beyond my ideas in point of quickness and perfection."

Becoming apprehensive that the additional weight which this pump put on the engine might have a tendency to twist the great lever, he hoped to guard against it in a large engine erected near Coventry, by using three pumps; two of them were fixed side by side, and the third placed over, in the space between them, received the hot water lifted by the two lower pumps. Less power was supposed to be expended by this arrangement, than by having only one pump from the surface of the piston which was exposed to the pressure of the atmosphere, having a much smaller area.

The practice of placing the air-pumps at the mine-end of the great lever was now also discontinued. The extraction of the air going on while the steam piston was descending, or making its working stroke, was less advantageous than placing the condenser pump on the opposite side of the axis, and drawing the air from the condenser before the descent of the piston; the vacuum beneath it by this means was perfected at the proper moment. Two condenser pumps, one made double the size of the other, were afterwards found sufficient for the largest engines, and in small machines a single pump performed the office.

The piston cylinder also underwent a great modification. The steam was made to flow into the cylinder from a pipe coming directly from the boiler, instead of being first conveyed into the space between the cylinder and its jacket. And Watt writes, that he had also laid aside the clumsy cast iron cylinder, and substituted a case of wrought iron plates, leaving an interstice about an inch and a-half all round, which extends to within six inches of the top, and three inches of the bottom: a small pipe, furnished with a cock, conducts steam from the boiler into the interstice. The effect of this casing was nearly equal to that of the outer cylinder; "but when we tried to lay aside the jacket altogether, we had no reason," says he, "to applaud our economy, for the consumption of fuel was considerably greater."

This required a new arrangement of the valves and pipes attached to the cylinder; *a*, the piston; *b*, the cylinder; *d*, the equilibrium pipe, and *i*, the equilibrium valve; *f*, eduction pipe and valve; *l*, the steam pipe proceeding from the

boiler; *m*, the steam valve; *n*, jacket; *o*, pipe conveying steam into the interstice between it and the cylinder. See plate marked WATT N, figure 1.

A vacuum being made under the piston, the steam from the boiler flows through the valve, *m*, and urges the piston downwards, until it reaches nearly the bottom of the cylinder, at which instant the steam valve, *m*, and the eduction valve, *f*, are shut, and the equilibrium valve, *i*, is opened; and the vapour which was above the piston and in the pipe, *d*, is now at liberty to flow under the piston, and into the pipe between the cylinder and the valve, *f*, which establishes an equilibrium between both sides of the piston. The counterpoise which is attached to the opposite end of the lever now acts to draw the piston upwards, and, as it rises, the steam which is displaced from above it flows through the equilibrium pipe beneath it. At the instant the piston arrives at the top of the cylinder, or has made what is called its returning stroke, the equilibrium valve is closed, and the steam and eduction valves are opened; this again allows vapour from the boiler to press on the piston, while the steam which now fills the space beneath it, rushing into the condenser, leaves a vacuum, and the piston descends as before.

In every form of the engine, it was considered to be essential to the most perfect action of the apparatus, that the condensation of the steam should be almost instantaneous; because the operation could only be performed at the instant when the piston was changing the direction of its motion, and should be perfect and complete from the moment the piston had a tendency to descend.

It occurred to Watt, that if the formation of

the vacuum could be made to commence at the moment when the piston had finished its loaded stroke, a more perfect exhaustion might be obtained; as then the entire interval in which the piston was ascending, might be employed to exhaust the cylinder of air, and steam, and water.

This it appeared to him could be accomplished by an alteration in the method of neutralizing the pressure on the piston, and he placed the valve, *i*, in the equilibrium pipe, *d*, near its insertion into the cylinder *b*. When the piston had made its loaded stroke, the steam valve *m* was shut, and the equilibrium valve *i* opened, and the steam which filled the cylinder rushed through the equilibrium pipe into the condenser: a vacuum was thus made above as well as below the piston; and it was drawn by the counterweight to the top of the cylinder; and, as the valve continued open during the whole time of its rise, a greater time was thus afforded for perfecting the vacuum, which thus permitted the steam at its first impulse to exert its power in the most favourable manner, in impelling the piston into the cylinder. See figure 2 in the engraving marked WATT N.

These inferences were far from being borne out by the result. The cylinder approximating in its temperature to that of the condenser, was cooled so much more than when the formation of the vacuum was more rapid, that more steam in entering it was lost than by the other mode, and the vacuum which had been forming during the whole neutral stroke, was not more perfect than that which heretofore had been produced during the mere instant which transpired between the change of the direction of motion in the piston. It was also found, that the

air insinuated itself into the cylinder between the piston rods and their boxes, and at the joints in the valves; and a small additional weight was also found to be necessary on the counterweight. The scheme, therefore, was given up, not as having failed, but as being somewhat less advantageous than when the piston rose in steam.

Watt, whose department it was, in his arrangements with Bolton, to visit the sites where his engines were to be erected, to enable him to design the connecting machinery to suit the local peculiarities, still assiduously continued his experiments upon the engine. But the same caution which hitherto distinguished his operations was always observed in putting the alterations, which from time to time occurred to him, into practice.

The anticipated improvement was first made upon an engine in daily use at Soho. When, after a long series of varied trials, it received the form pointed out by experiment to be the most perfect, it was carefully copied into the model, from which Bolton, without the slightest deviation, proportioned and arranged the parts of all the engines that he manufactured for sale. So slowly were these innovations adopted, that, for years successively, the standard model remained unaltered. Watt's opinion of the practice of substituting analogy for experiment will be best gathered from one of his letters: "I am tormented," says he, "with exceedingly bad health from the operation of an anxious mind, the natural consequence of staking every thing upon the cast of a die; for in that light I look upon every project, that has not received the sanction of repeated success."

His reputation as a man of genius gained pro-

digiously by this wariness; for his inventions, when they came before the public as it were fresh from his hand, were so finished and perfect, that his most gifted rivals were unable to add to his design or rectify its proportion.

It was also of incalculable advantage in inspiring confidence in Watt and Bolton's judgment as engineers. The greatest danger they had to fear, was from an unsuccessful or even doubtful experiment. The mass of prejudice they had to encounter, would have acquired fresh vigour by every, even meritorious, effort that fell short of perfection.

The inconvenience of this circumspect method of proceeding, although foreseen, could not at all times be guarded against. The projects during their developement necessarily became known to many. The cupidity that always accompanies dulness, was thus sometimes enabled to claim merit for contrivances that had for years been practised by another. Watt is admitted to have had an engine at Soho, acting on the expansive principle, as early as 1776. In 1778, he erected another on the same construction, to pump water for a public company near London; and although another mechanic, three years after this later machine was in operation, took out a patent for a similar contrivance, we will describe it as an invention worthy of Watt's genius, and which only his wonderful skill could have called so perfectly into existence.

The expansive action will be easily understood, by supposing a piston placed at the top of an enclosed cylinder, which has one end communicating with a boiler, and the other with a condenser. Watt allowed steam to flow into the cylinder until the piston had been carried for a

certain depth into the cylinder; he then closed the steam-pipe, so that no more vapour could enter from the boiler; that which was in the cylinder expanding in volume, continued to press the piston downwards, until it occupied the entire capacity of the cylinder.

When the steam ceased to flow from the boiler, the portion in the cylinder exerted less and less power every instant; so that by the time it had expanded into twice or thrice its first volume, it exerted only one-half or one-third of the power it did at the beginning.

This decreasing power opened a steady and simple mode of regulating the tendency to an accelerated motion in the piston; and to prevent the injurious effect of bringing it to a state of rest, each stroke, at the instant it had acquired its greatest momentum, the accelerating force of gravity was diminished and neutralized by a decreasing impulse being impressed upon the moving body. For this purpose, the passages through which the steam entered from the boiler into the cylinder, and from the cylinder into the condenser, were enlarged or diminished by raising or lowering the valves placed in them. The valve, for instance, which admitted the steam into the cylinder, was opened so much as to let the steam flow slowly above the piston after a certain interval, or it was altogether closed to allow the steam to act with its entire expansion; and after the piston had made its loaded stroke by narrowing the passage through the equilibrium valve for the steam, the vapour which was displaced by the piston in its neutral stroke, was made to flow so slowly as to check the tendency of the counterweight, to produce a variable motion.

This facility of equalizing the motion, although a point of great value, not only as it regarded the proper application of the power, but as it influenced the durability of the mechanism by preventing concussions which would have shaken it to pieces, was but of minor importance when compared with the saving of fuel that was made, by allowing the expansive force of a portion of vapour to perform what had been hitherto accomplished by the unimpaired elasticity of the entire measure.

If, for example, steam of the temperature of 212° flows into a cylinder six feet long until the piston has been moved eighteen inches downwards, when this quantity has expanded into double its former volume, and in doing so has pressed the piston to the middle of the cylinder, it will exert a pressure of not more than seven pounds on each square inch area of the surface of the piston. When the piston has been depressed another eighteen inches, the vapour will have expanded into three times its original bulk, it will then urge the piston downwards, with a force of not more than four pounds and a half on each square inch; and when it has reached the bottom of the cylinder, and expanded into four times its original bulk, it will not exert a greater energy than about $3\frac{2}{3}$ pounds on each square inch. If now we calculate the varying power of the steam from the commencement to the termination of its stroke, beginning with a force of fourteen pounds, and ending with $3\frac{2}{3}$ pounds, it will have exerted an average pressure of nearly $8\frac{1}{3}$ pounds on each square inch of the piston.

But if the vapour had been permitted to flow freely into the cylinder, as fast as the piston descended, it would have pressed it with a force of

fourteen pounds during the entire stroke of the piston.

We thus see that one and a half feet of steam, acting expansively, has pressed eight and a quarter pounds through six feet; while six feet of steam operating with its energy, uniform and unimpaired, has only carried fourteen pounds through six feet;—shewing that more than half of the whole steam has been saved, by making it act expansively.

A mere alteration of the tappets in the plug-frame, so that the supply of steam should be shut off, when the piston had moved through a third or other proportion of its entire stroke, was all that Watt found necessary to introduce this fine discovery into his common mechanism.

It will be apparent that when steam is to be employed expansively, a larger cylinder will be required to develop the same power, than if the vapour were to act with its power undilated throughout; and from the greatest effect being obtained in this mode, when the first portion of steam is small in comparison with its final enlargement, it will be evident that its use, in the most favourable case, will in practice be almost unobtainable, from the cumbrous size of the vessels necessary to ensure its action; and Watt also found, that, in addition to this inconvenience, these large vessels occasioned a loss of power from their exposing a very great surface to the condensing influence of the atmosphere; and he also found this loss bore a much greater proportion to the power that was gained, than he at first anticipated. He usually operated with steam of a force equal to seventeen or eighteen pounds on the inch, or three or four pounds above the atmosphere pressure, and it was seldom allowed

to expand beyond some fractional part of its volume.

The average pressure on the piston was always nearly equal to the average load, but he found that the acquired momentum of the ponderous masses of the lever-beam prevented any interruption to the motion of the engine from a small excess in the load.

And this tendency to acceleration in the motion of the piston, which has been described as a great defect in his and in the atmospheric engines, and which elicited much ingenuity to render it evenly, he now called to his aid, as a means to produce a uniform movement in a machine whose motion was unequal, from being impelled by steam of varying energy. And so skilfully was this rectification applied, that, in the Shadwell engine, an almost perfectly equable movement was given, by balancing the irregularity produced by the loss of energy in the expanding vapour, by an irregularity arising from an increase of power by the action of gravity.

Watt also proposed some mechanical combinations to produce an equable motion in the piston of an expansive engine.

In figure 1, two wheels, *r*, *s*, are connected by a rod or chain, *x*, fixed to the end of the levers *e*, *i*. These wheels are in the position as if the piston, which is attached by a chain to the circumference of *r*, were at the top of the cylinder. As it descends, the lever, *e*, is drawn towards the point, *c*, which increases its effective length, and Watt directed that this increase should be adjusted to compensate for the decreasing force of the steam on the piston, on account of its expansion within the cylinder. And as the load on the pump was

the same from the beginning to the end of the stroke, the lever, *i*, decreases in its length as *e* increases; so that when the steam is exerting the greatest force on the piston, the leverage of *e* is least, and that of *i* greatest; and when the steam presses with the least energy on the piston, the power exerted by the lever, *b*, to raise the lever, *i*, is greatest.

The second method is by means of a chain wound upon one spiral, *a*, or yielding lever, and wound off another spiral, *b*, as the piston descends; the chain, *x*, (figure 4) passes over *b*, and the pump rod is fastened at *c*; as the piston descends it acts to shorten *b*, and lengthen *a*.

In the same manner, when the piston fixed to the chain, *a*, (figure 2) descends through equal spaces, the pump rod attached to *c* rises through unequal spaces. In figure 3, the centre or point of suspension of the lever beam, *c*, is made to change its place during its vibration, so that the end, *e*, to which the piston rod is suspended, is nearer the axis, as the piston begins to fall, than at the termination of its movement; *m*, is a hollow curve of wood or metal, fixed to the lower side of the working beam; *n*, friction roller, furnished with teeth or cogs to prevent its sliding as it rolls between the curve and the plane of support, *o*. This roller is divided into three parts, the two extremities of which roll on the plane, *o*, and the lever beam is on its centre. When, by the fall of the piston, the end, *i*, of the working beam is pulled downwards, the roller proceeds towards that part of the curve which is highest and now nearest to *e*, and thereby shortens the lever, by which the pumps resist the piston, and lengthen the lever, by which the piston acts on the pumps

as the steam expands in the cylinder, in any ratio that may be required, according to the form which is given to the curve.

The sixth figure shows another mode of obtaining the same result, by means of a heavy cylinder, *a*, of iron, which rolls in a hollow curve, *c*, on the back of the working beam *d*; so that the centre of gravity of the beam, at the beginning of its motion, lies nearer to the pump end, *f*, of the beam: but, as the piston descends, the cylinder rolls towards the other extremity of the beam, and acts in aid of the decreasing energy of the vapour. A more complicated variety of this contrivance is shown in figure 5, in which the piston is attached to the curved beam, *a*; this acts on the pump beam, *c*, by means of a rod, *d*, attached to a friction wheel, *e*, which rolls on the pump lever. By the motion of this wheel, at the descent of the piston, the leverage is increased as the steam weakens its pressure.

Another scheme, which will be easily understood without a diagram, was, to cause a quantity of water to oppose the ascent of the piston in the beginning of its stroke, and to assist it in the latter part. Two cylinders, open at top and bottom, each fitted with a piston, have their rods suspended from the opposite ends of the lever beam. At the beginning of the stroke the weight of the water on one of the pistons produces the required resistance: but as the beam rises, it lifts the water, which flows through a pipe upon the piston in the other cylinder, which thus becomes loaded in proportion as the other is relieved. The adjustment shown in the figure 7 has a weight, *a*, placed considerably above the axis, *b*, of the beam, *c*. At the commencement of the

stroke, the centre of gravity of the lever lies nearer the pump end, *i*, of the beam, and thus acts against the force of the piston; but, during the stroke, it inclines to the other side of the axis, and thus acts to increase the energy of the vapour.

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WATT SINGLE IMPULSE ENGINE.

WAT[illegible] FIRST ENGINES

CECIL'S ENGINE

WATT DOUBLE IMPULSE ENGINE

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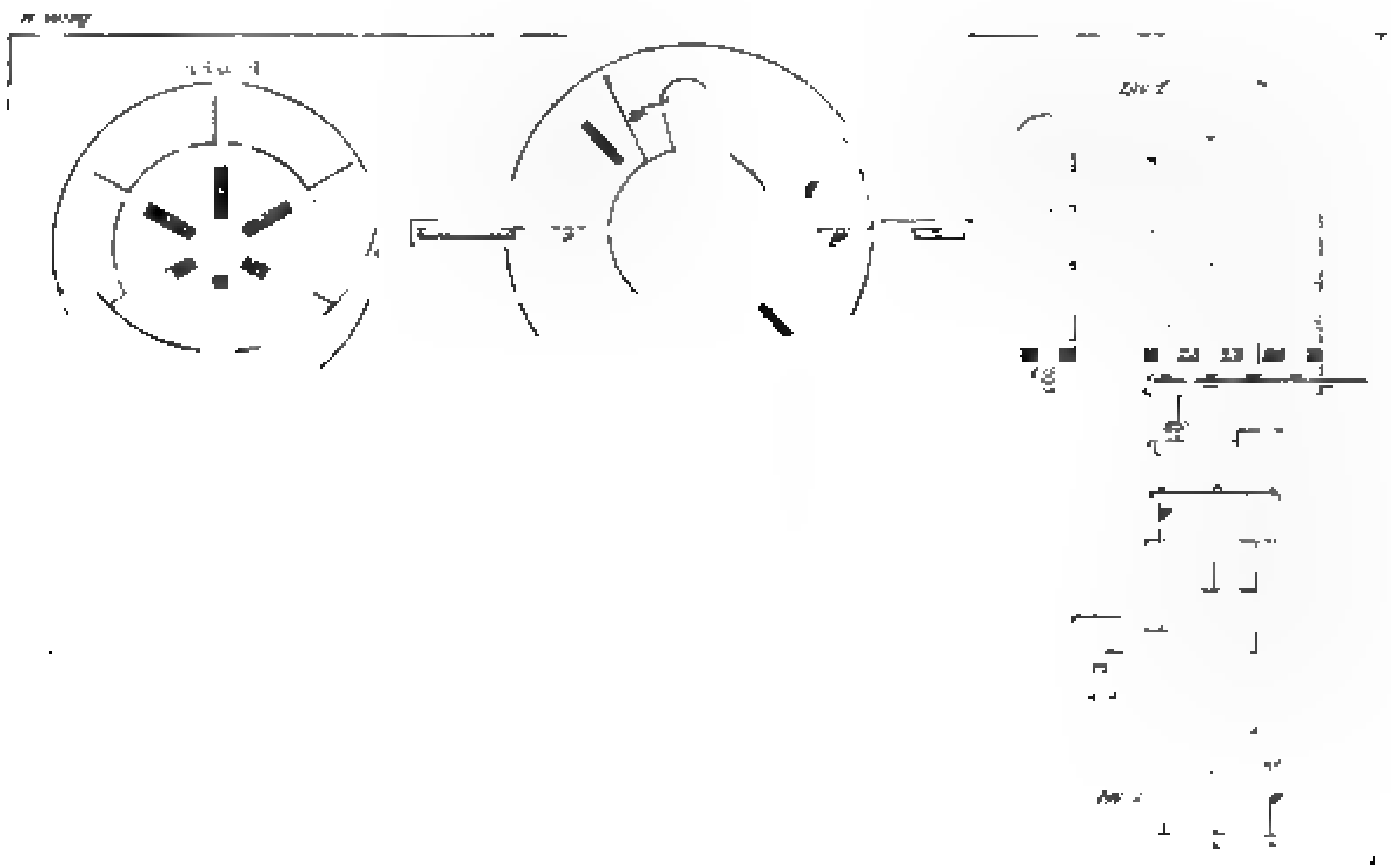

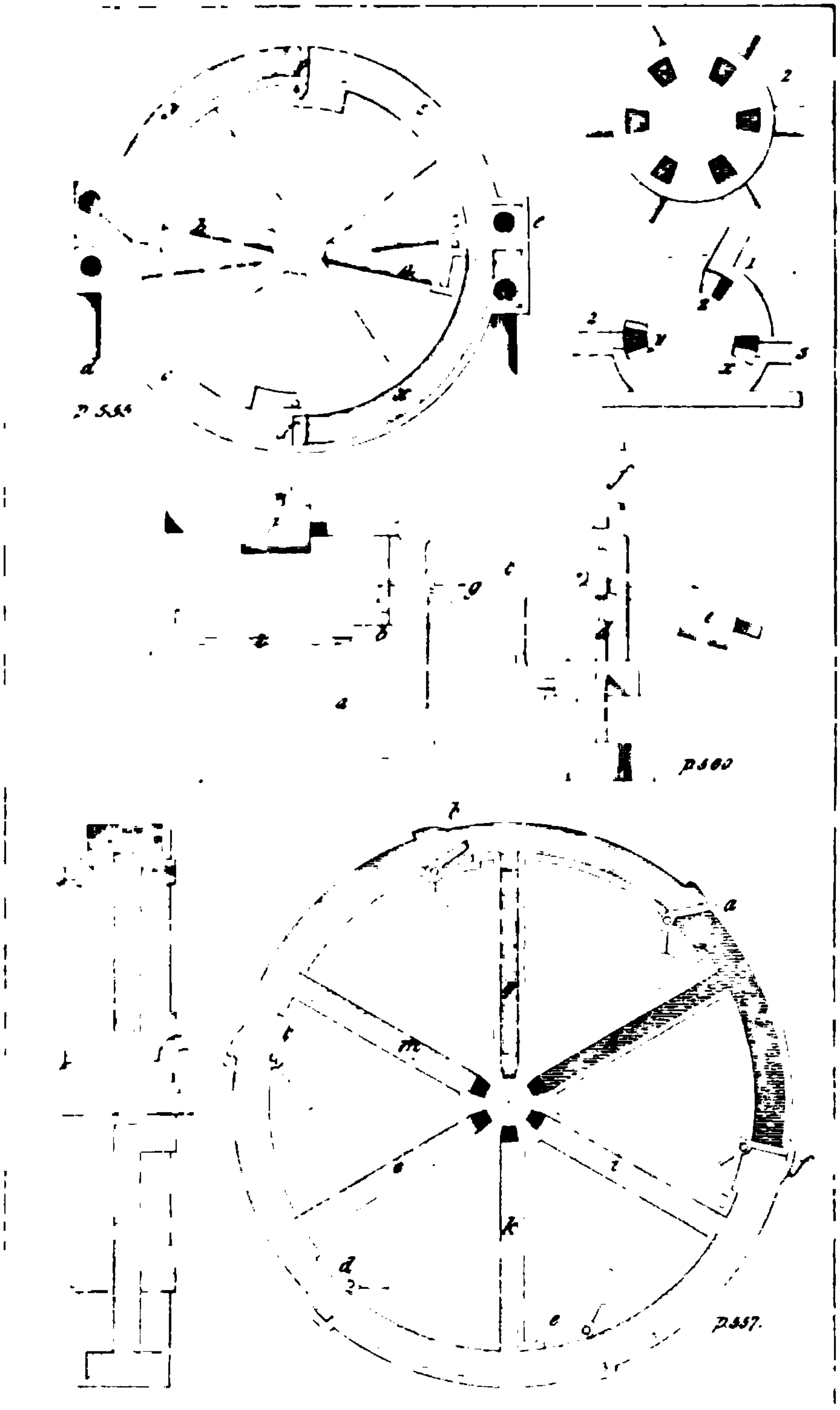

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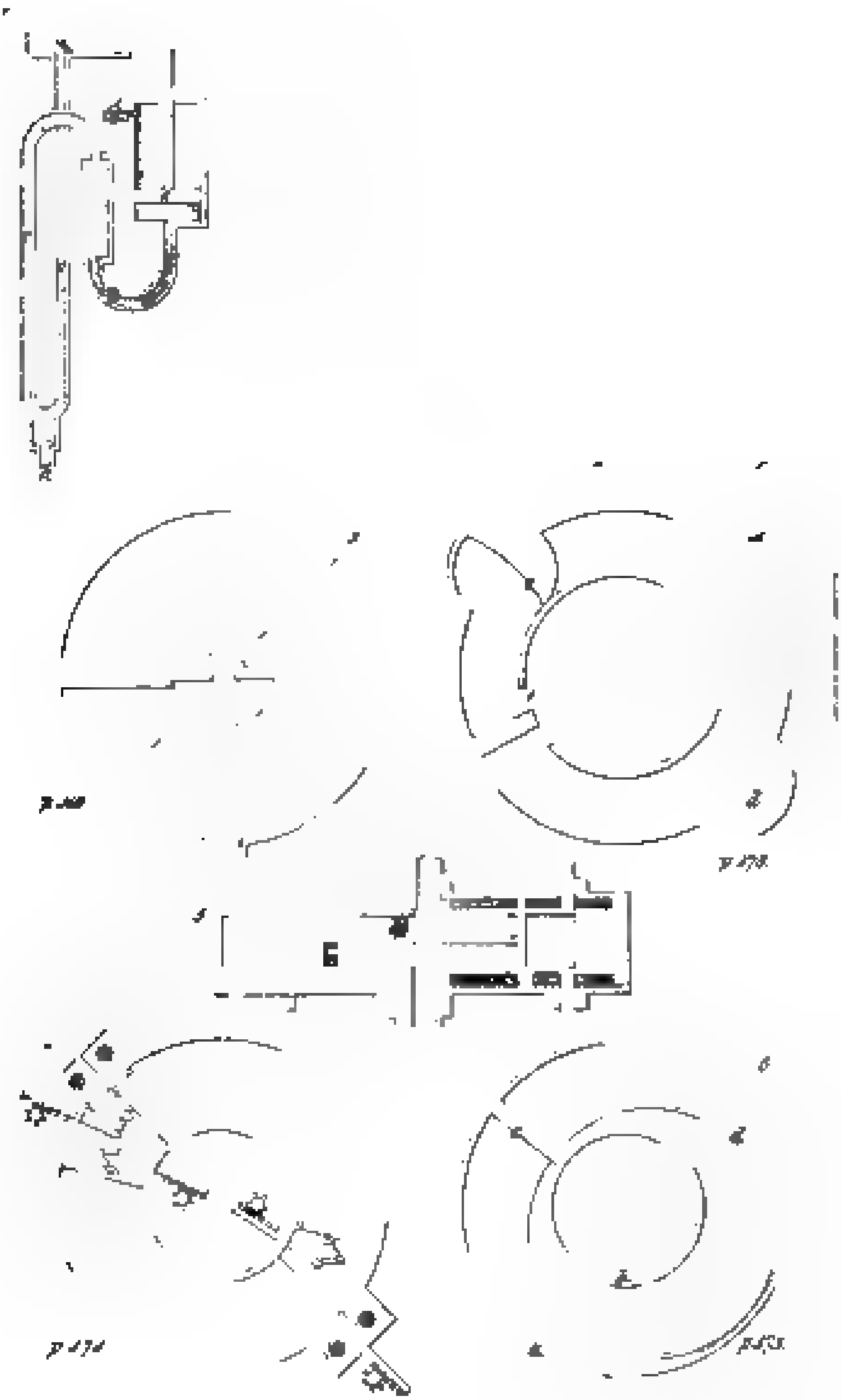

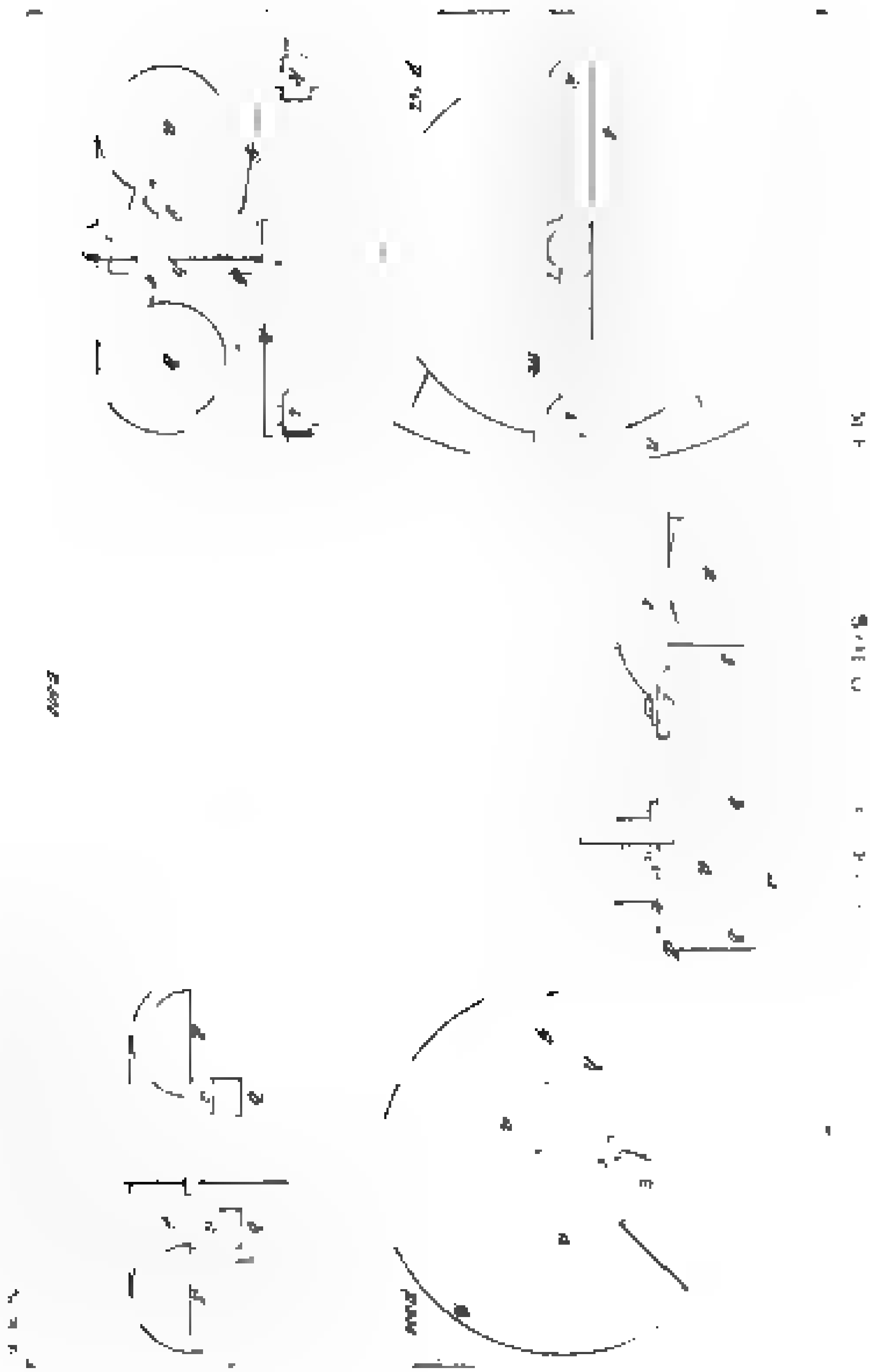

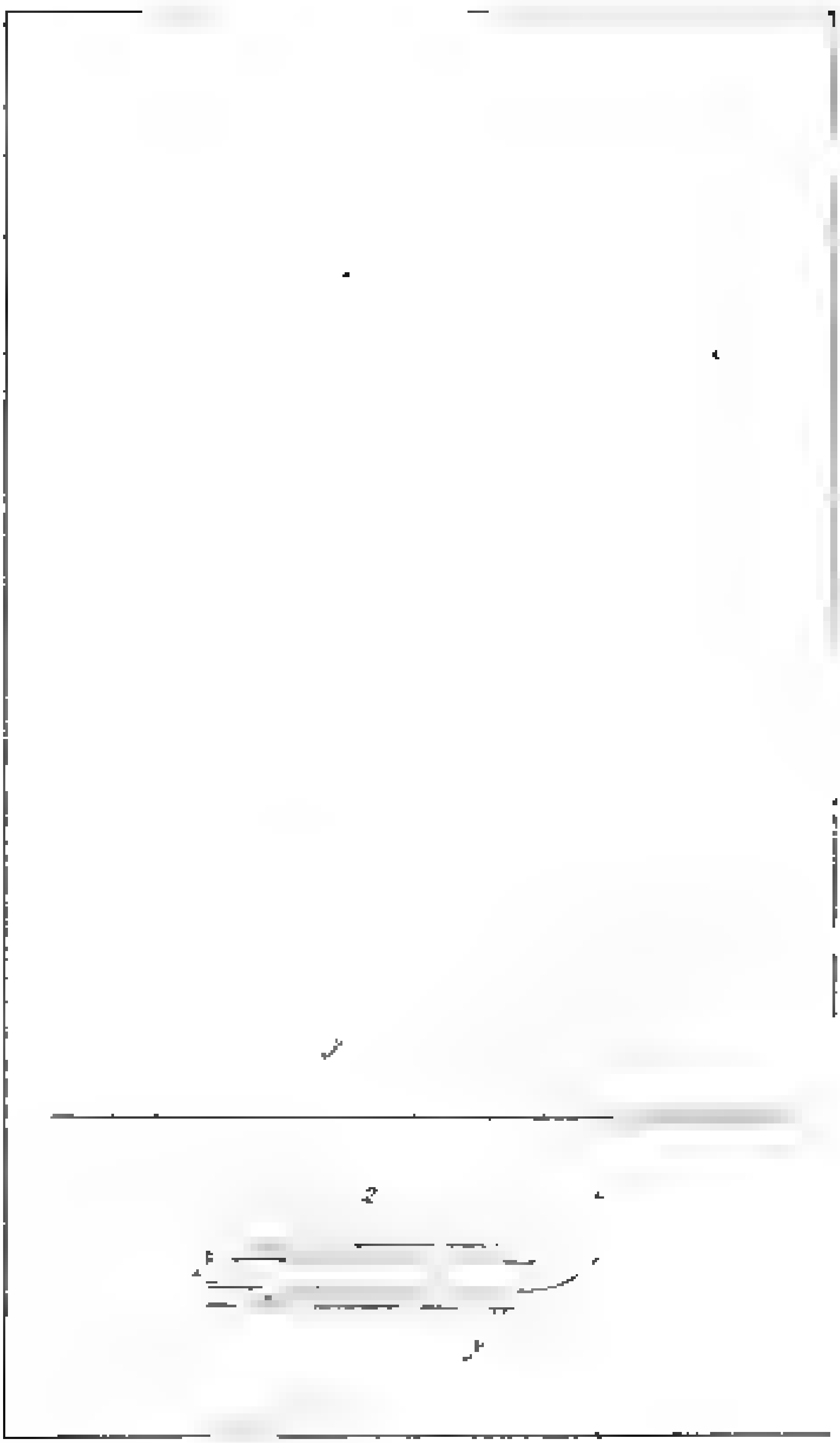

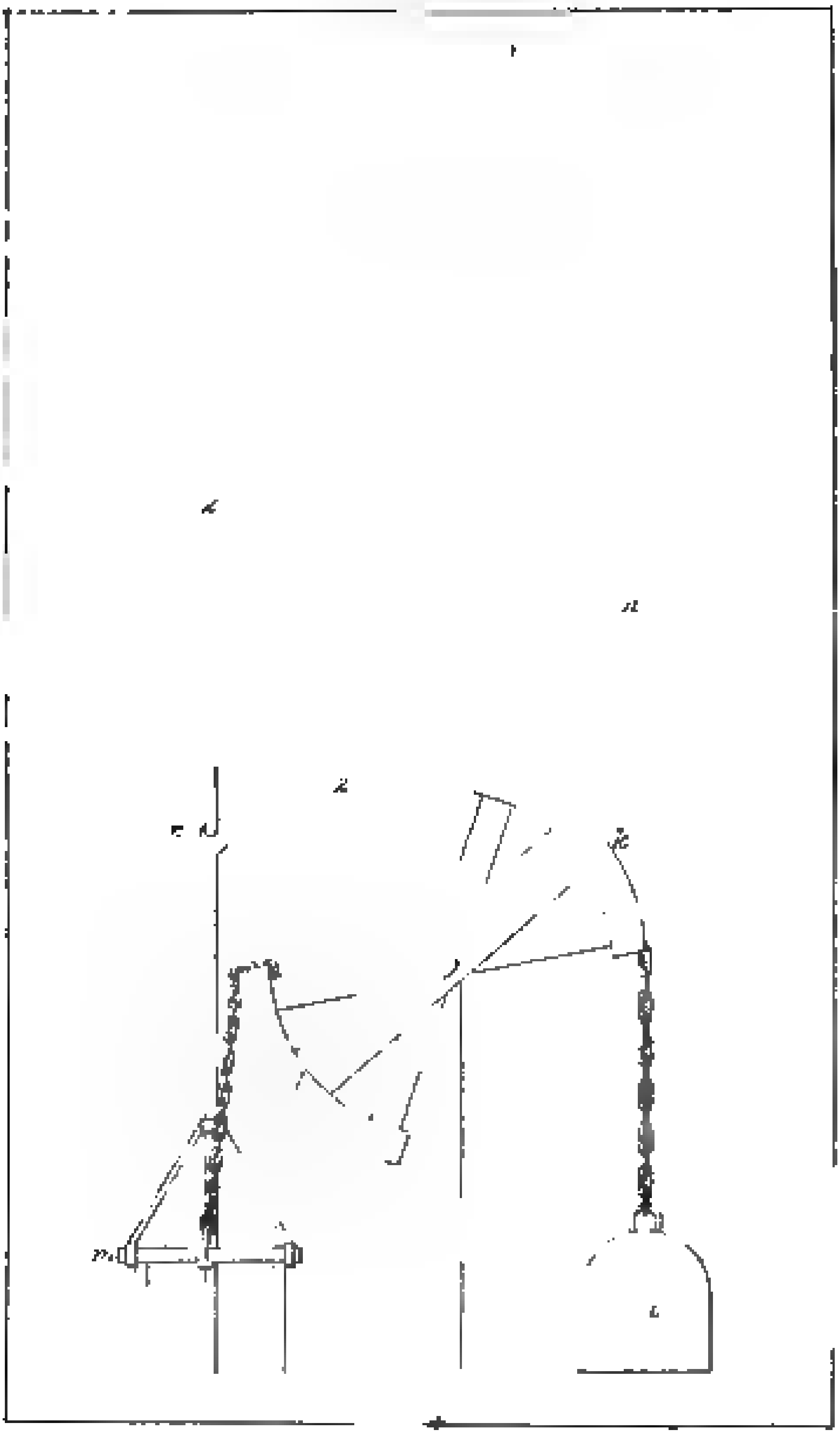

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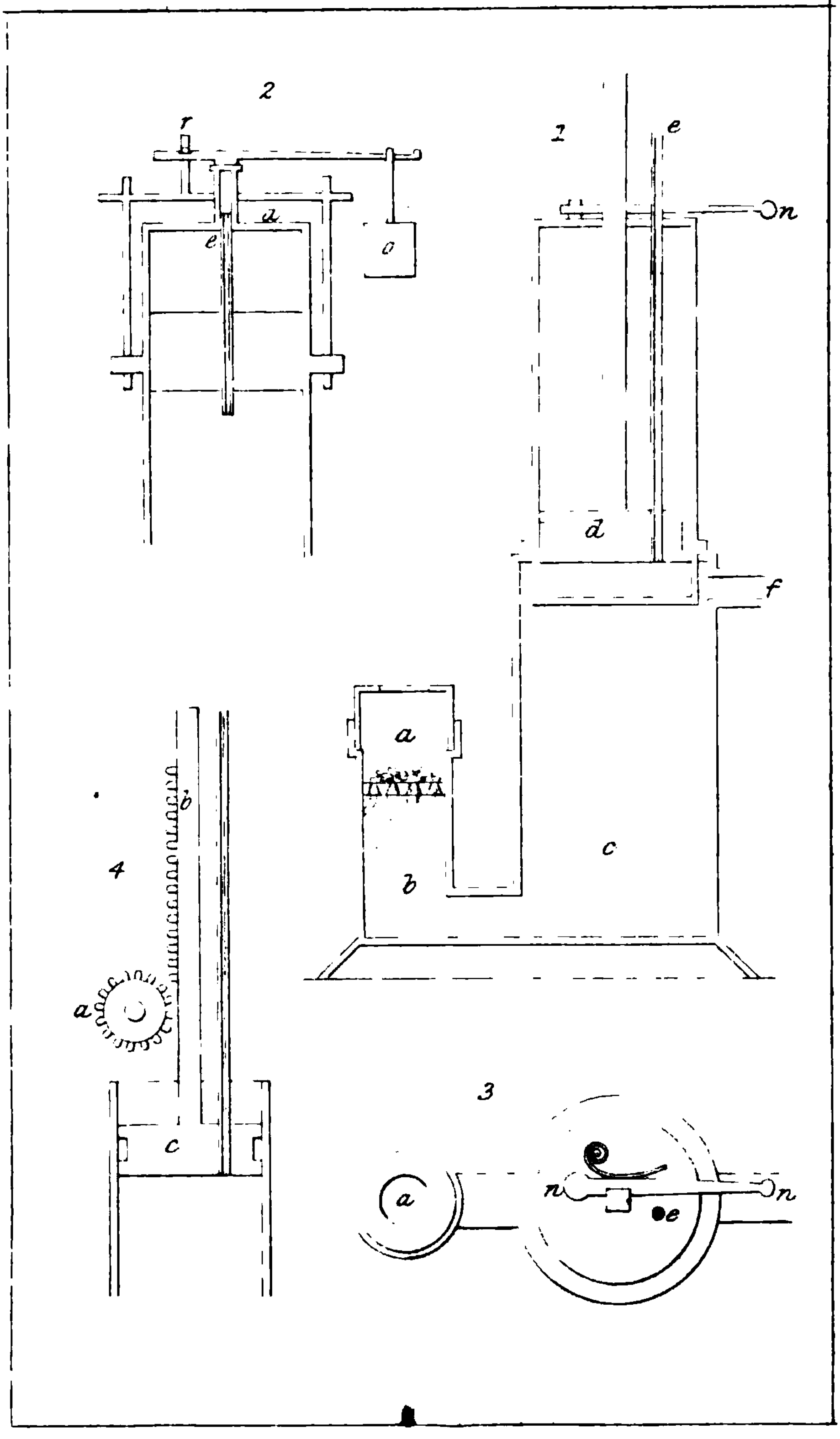

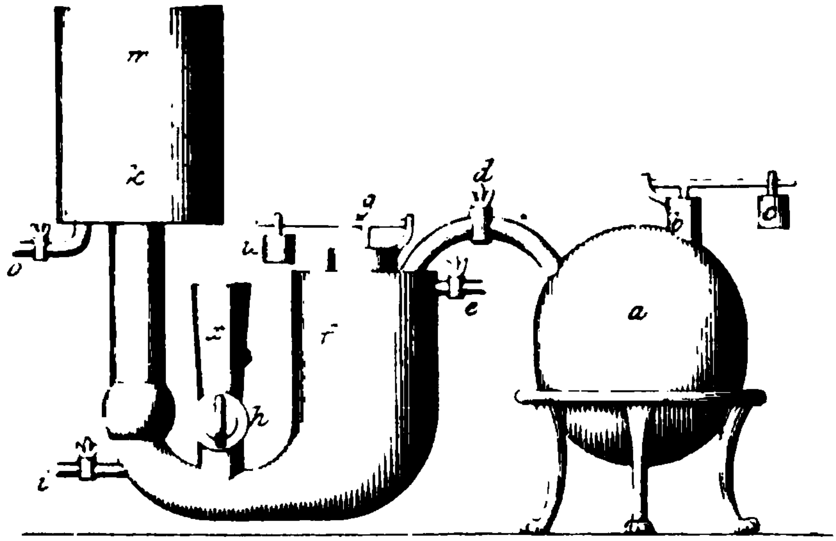
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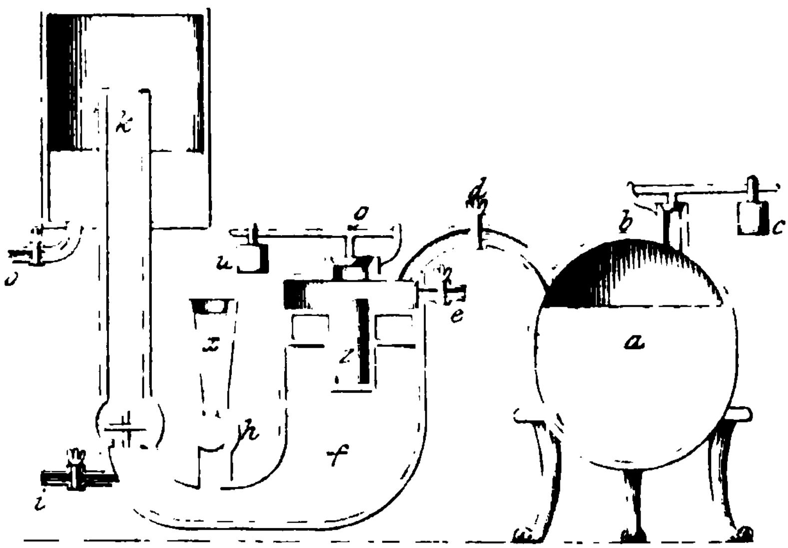
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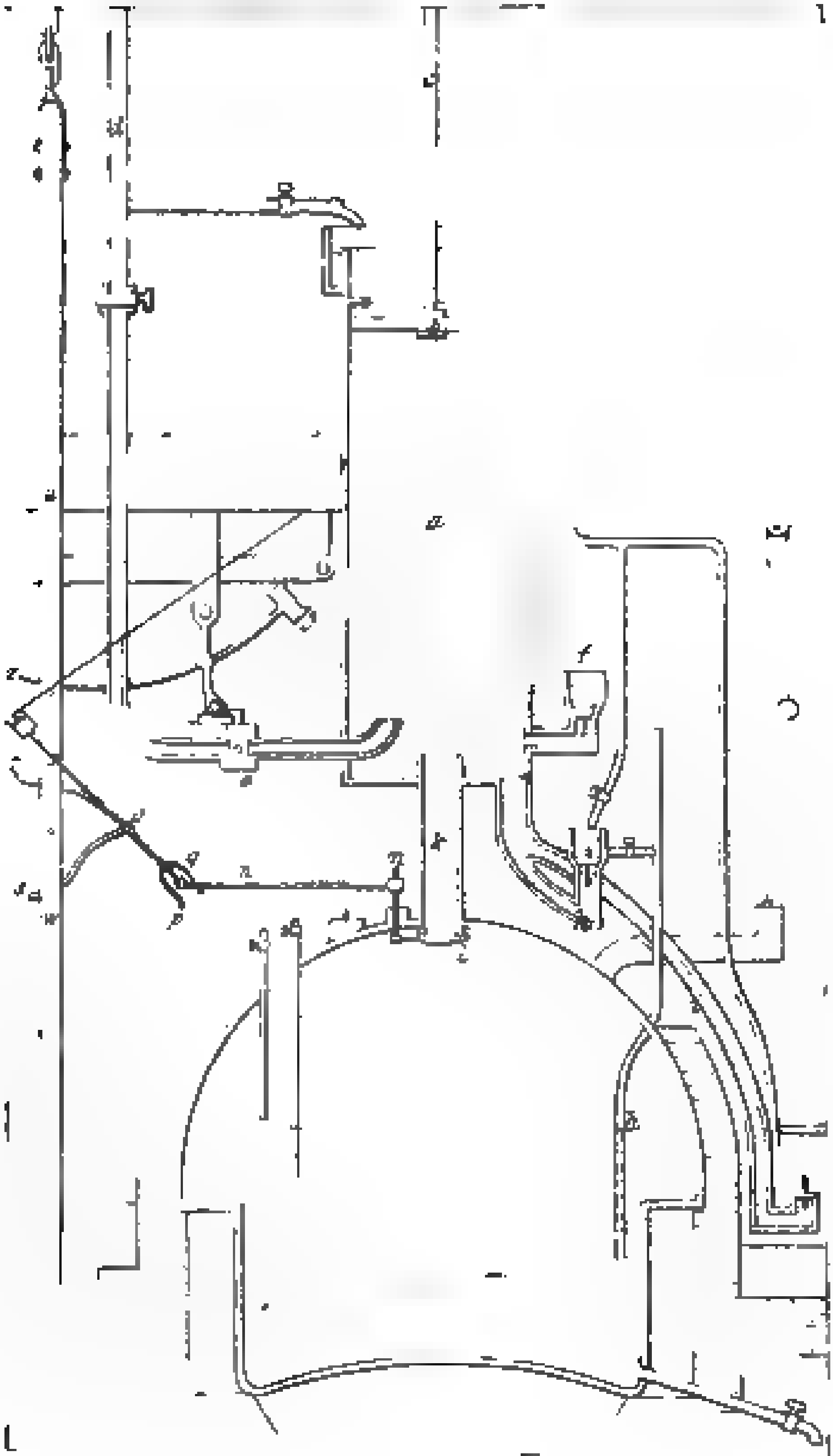

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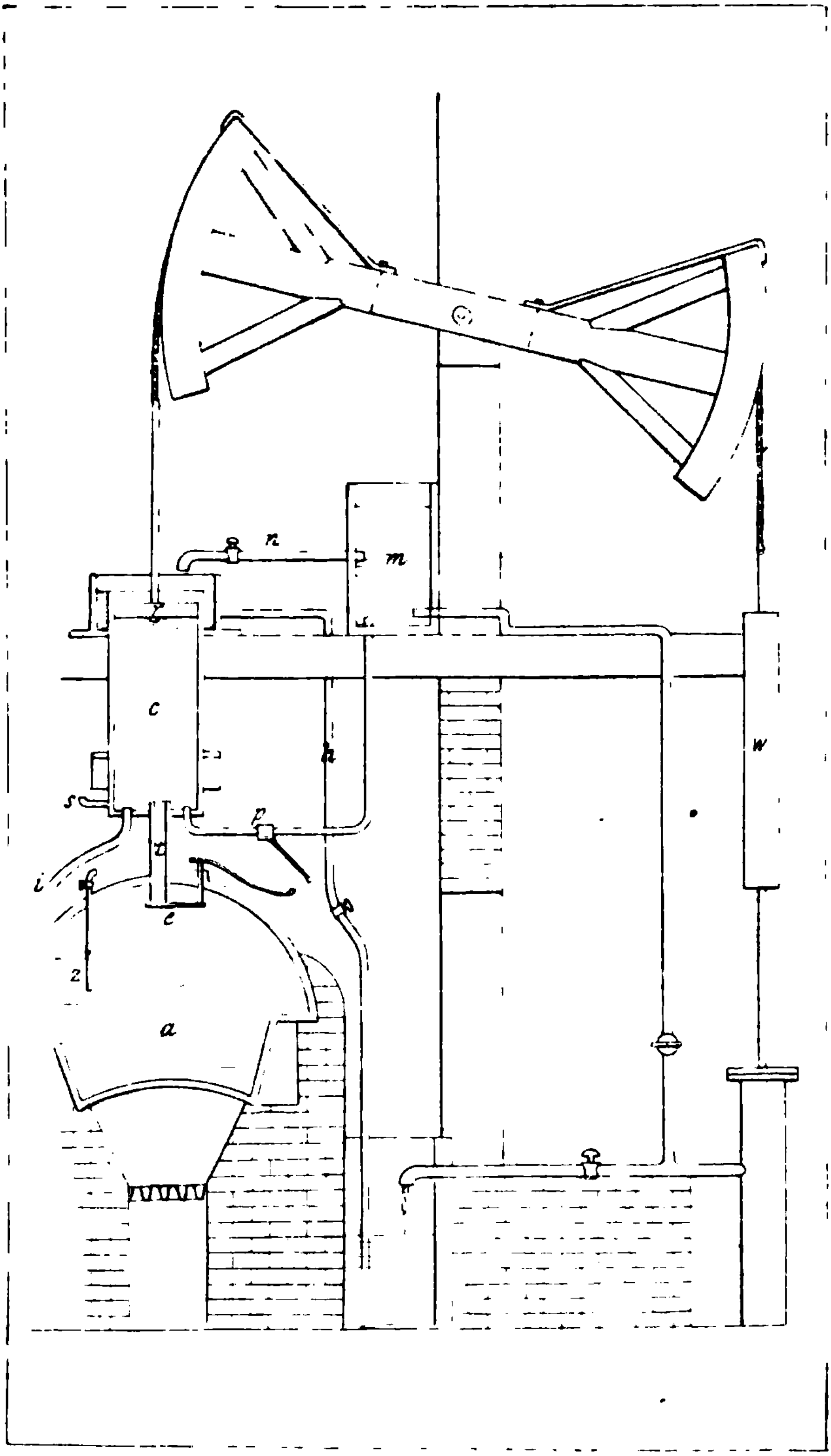

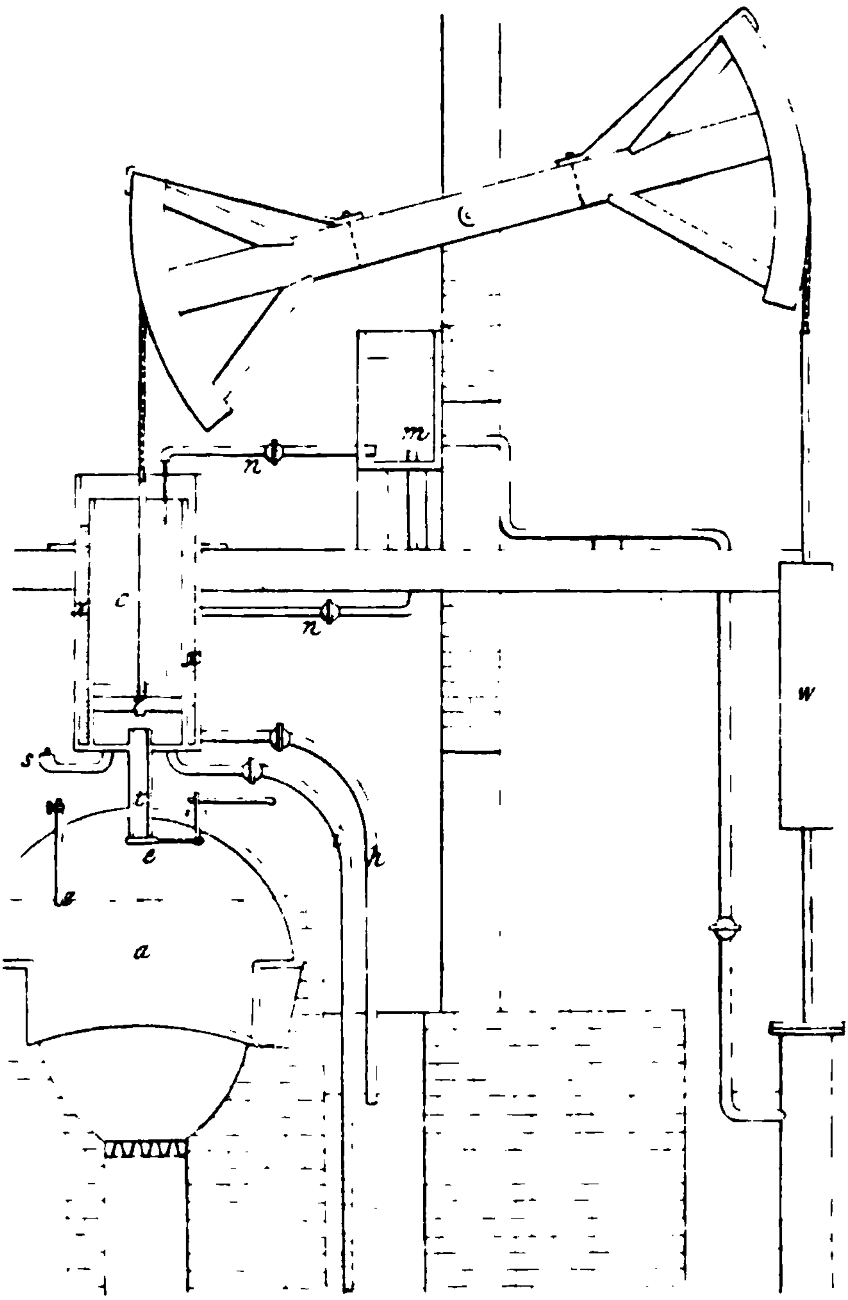
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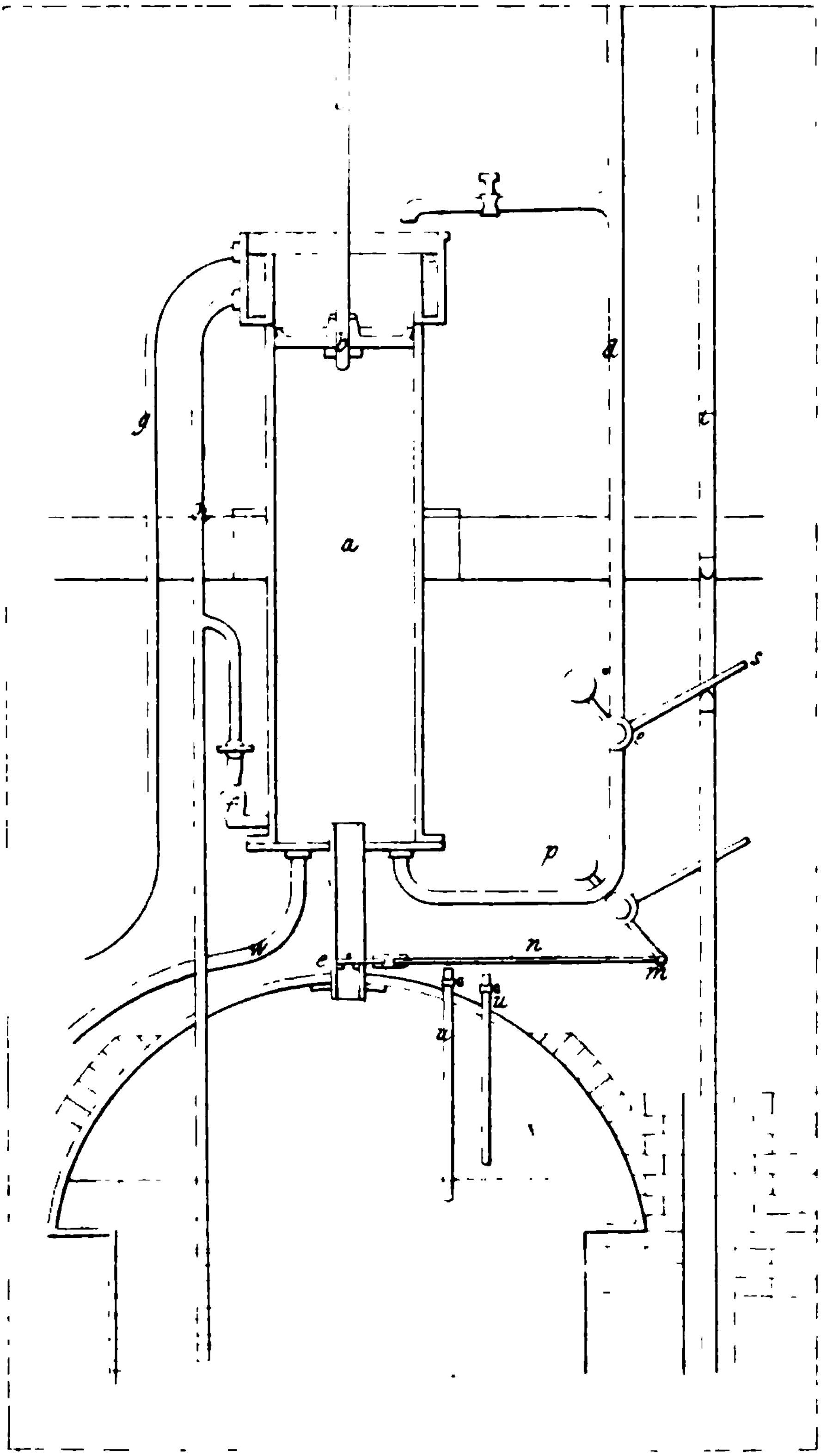
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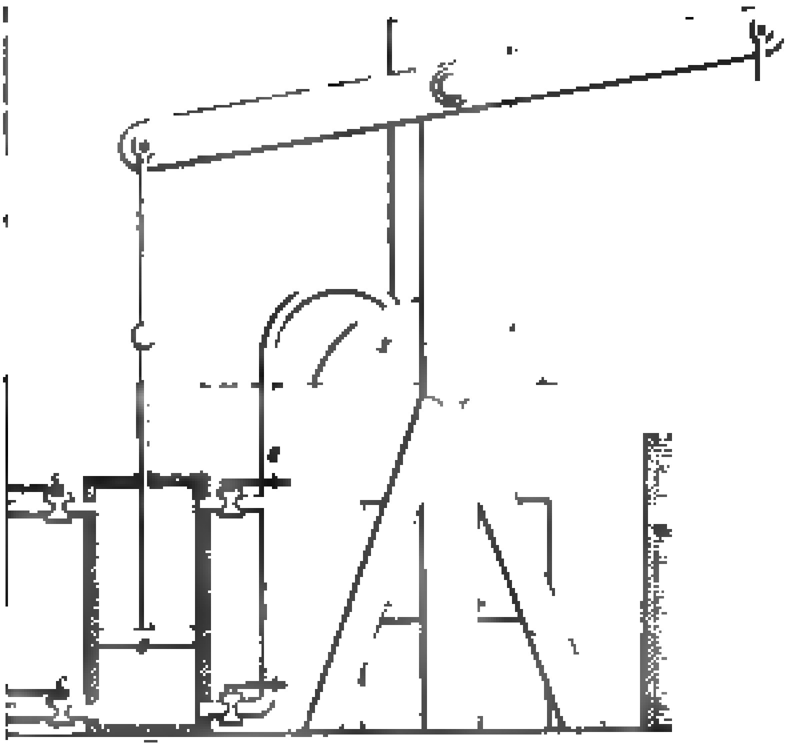

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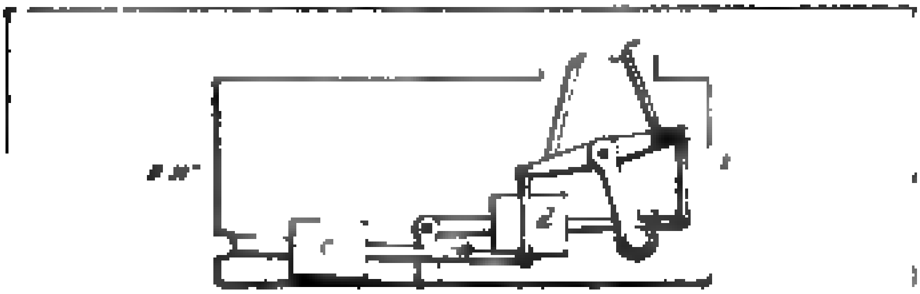
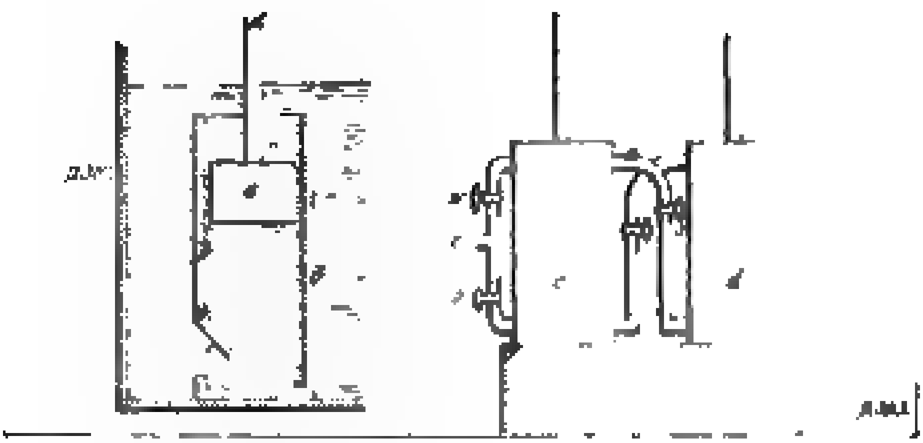
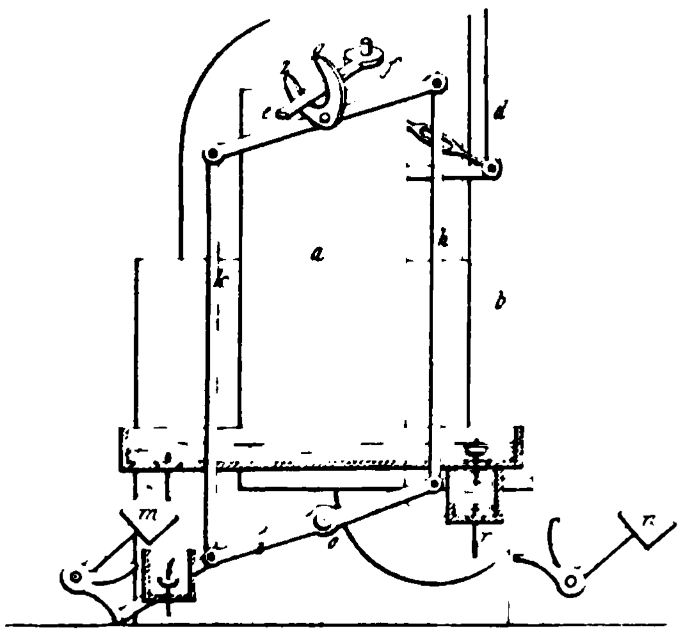




NEW STEM F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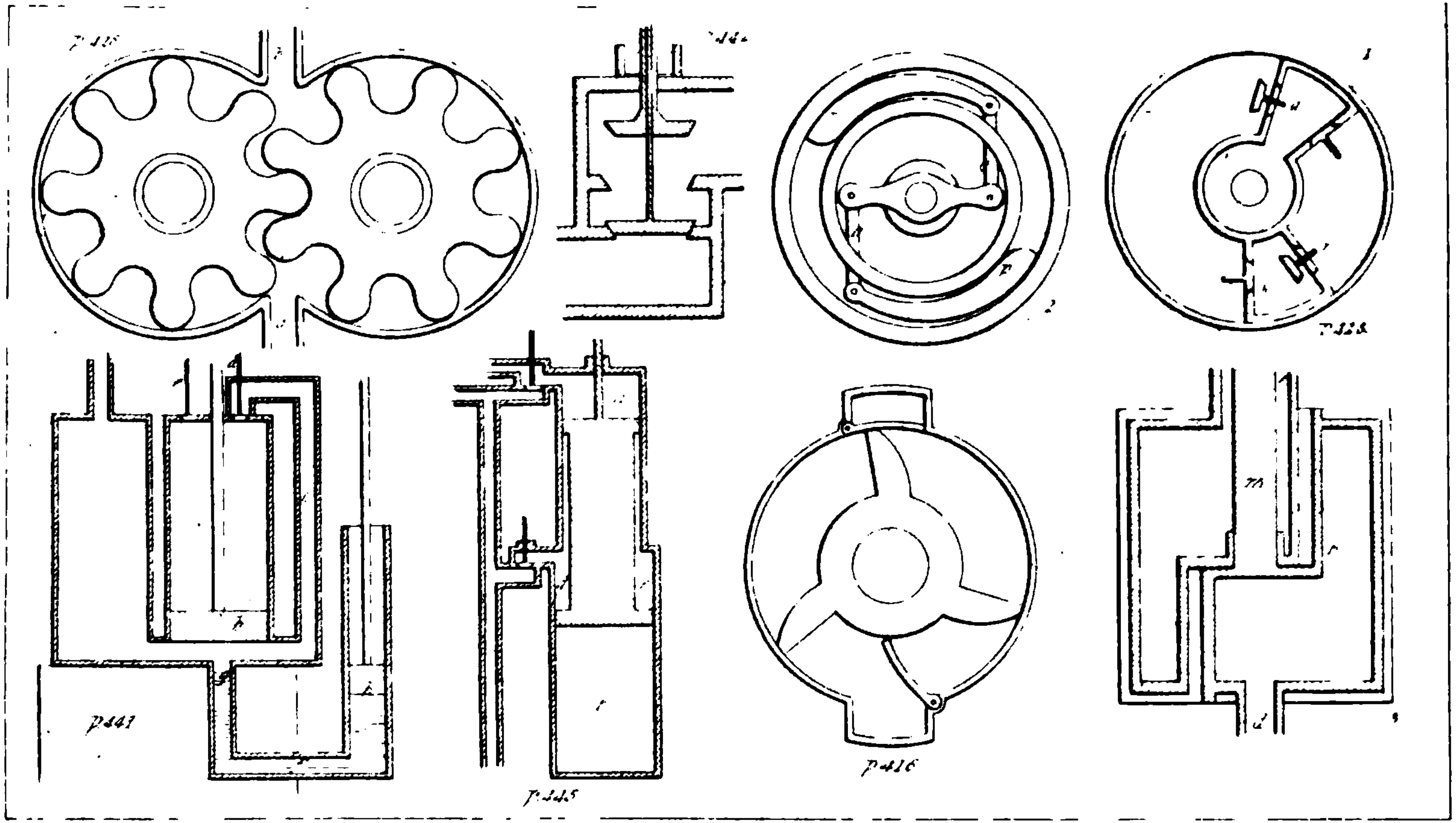
ROTARY MOTIONS. MURRAY. ROBERTSON. [illegible] BLOWER



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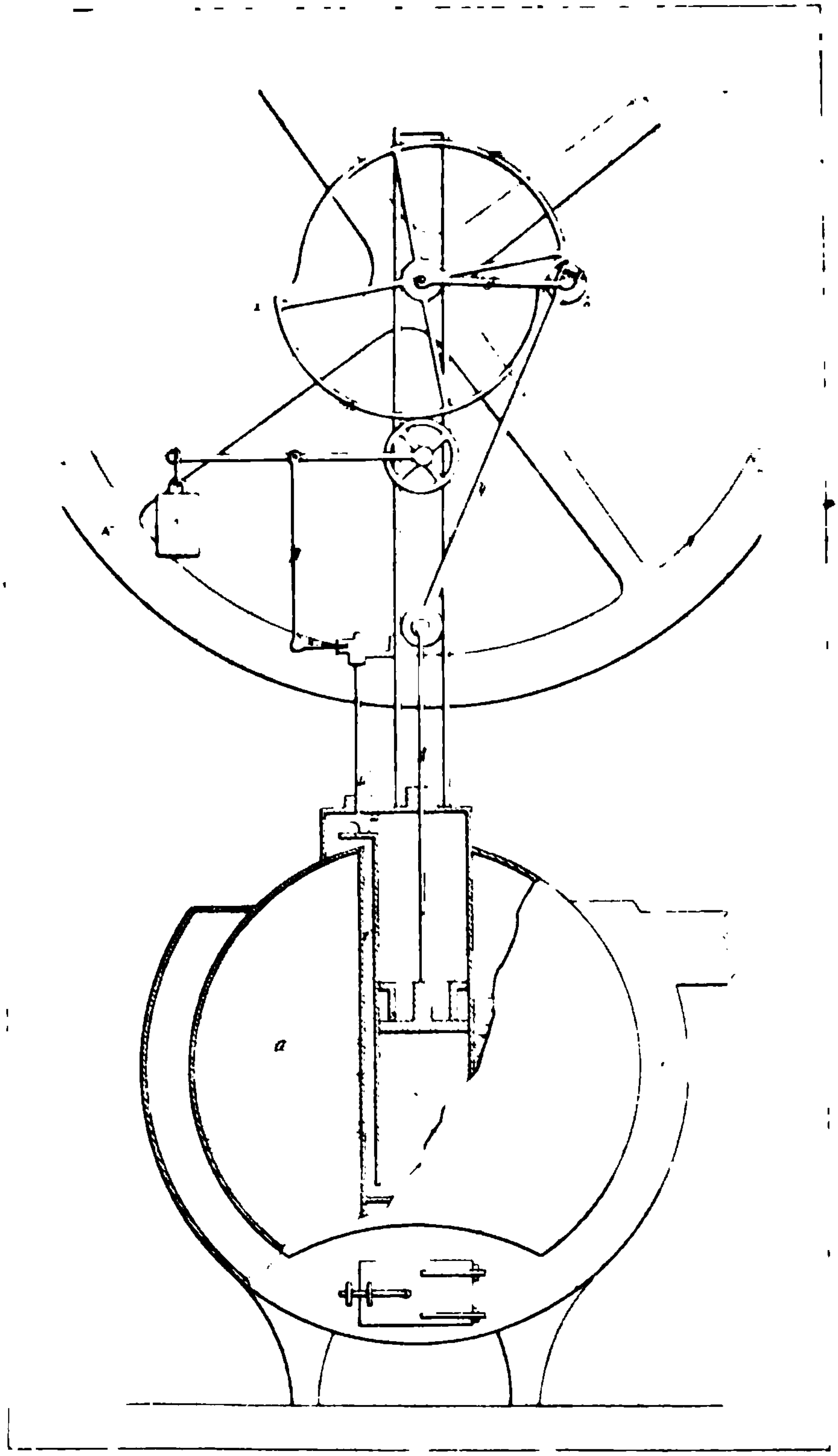

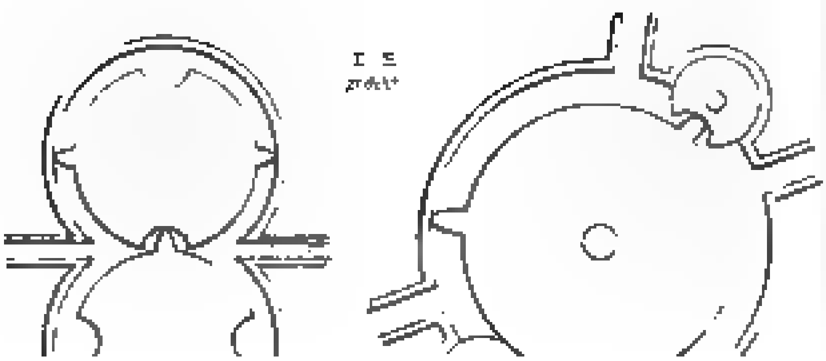

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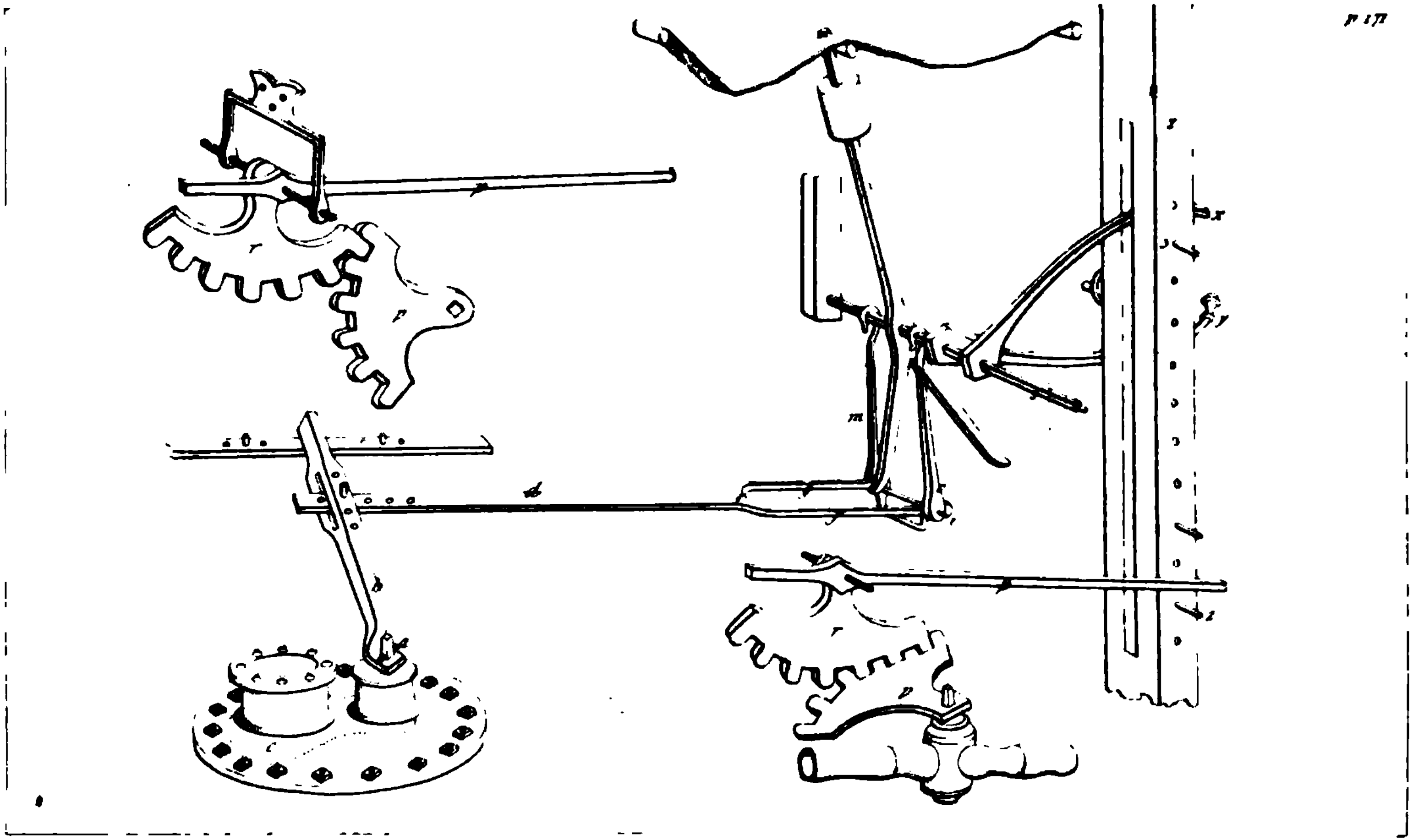
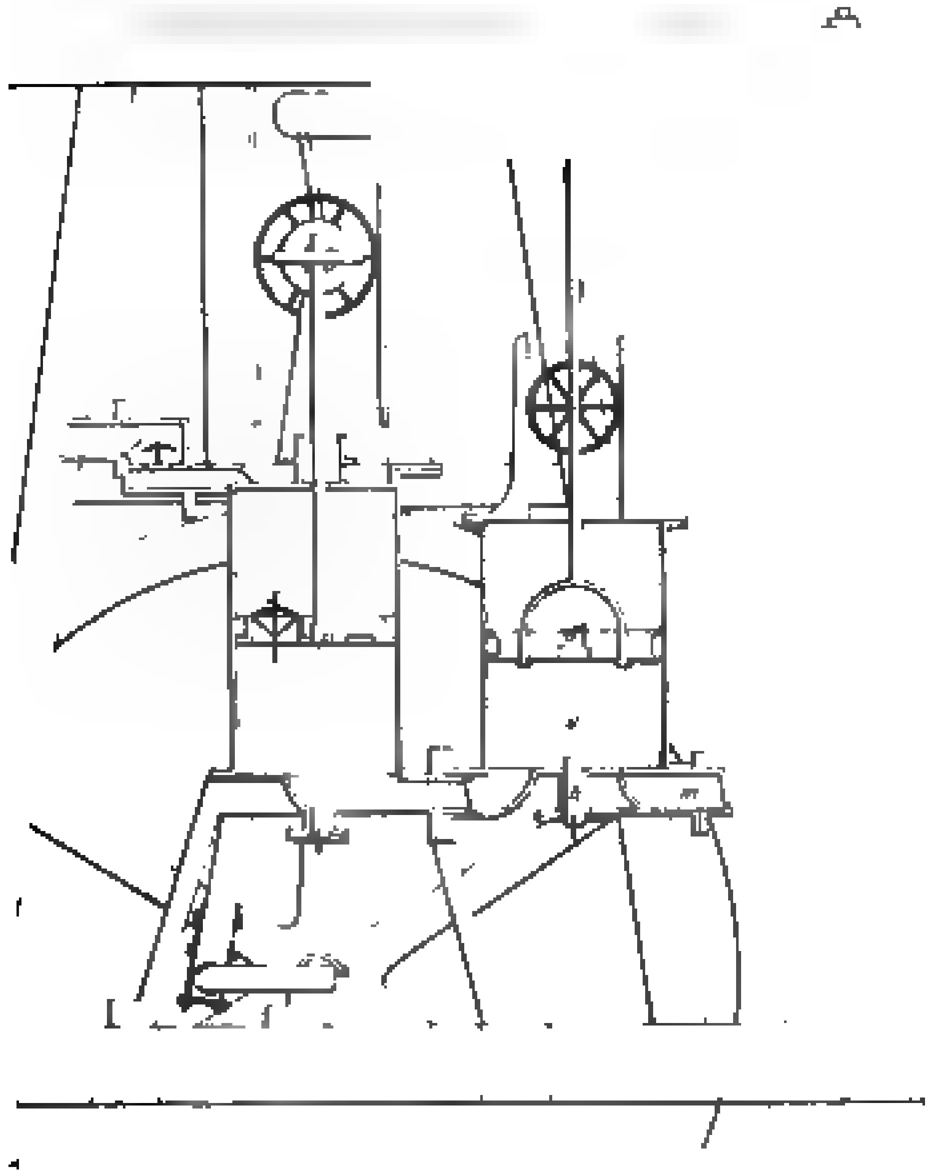


SADLERS ENGINE



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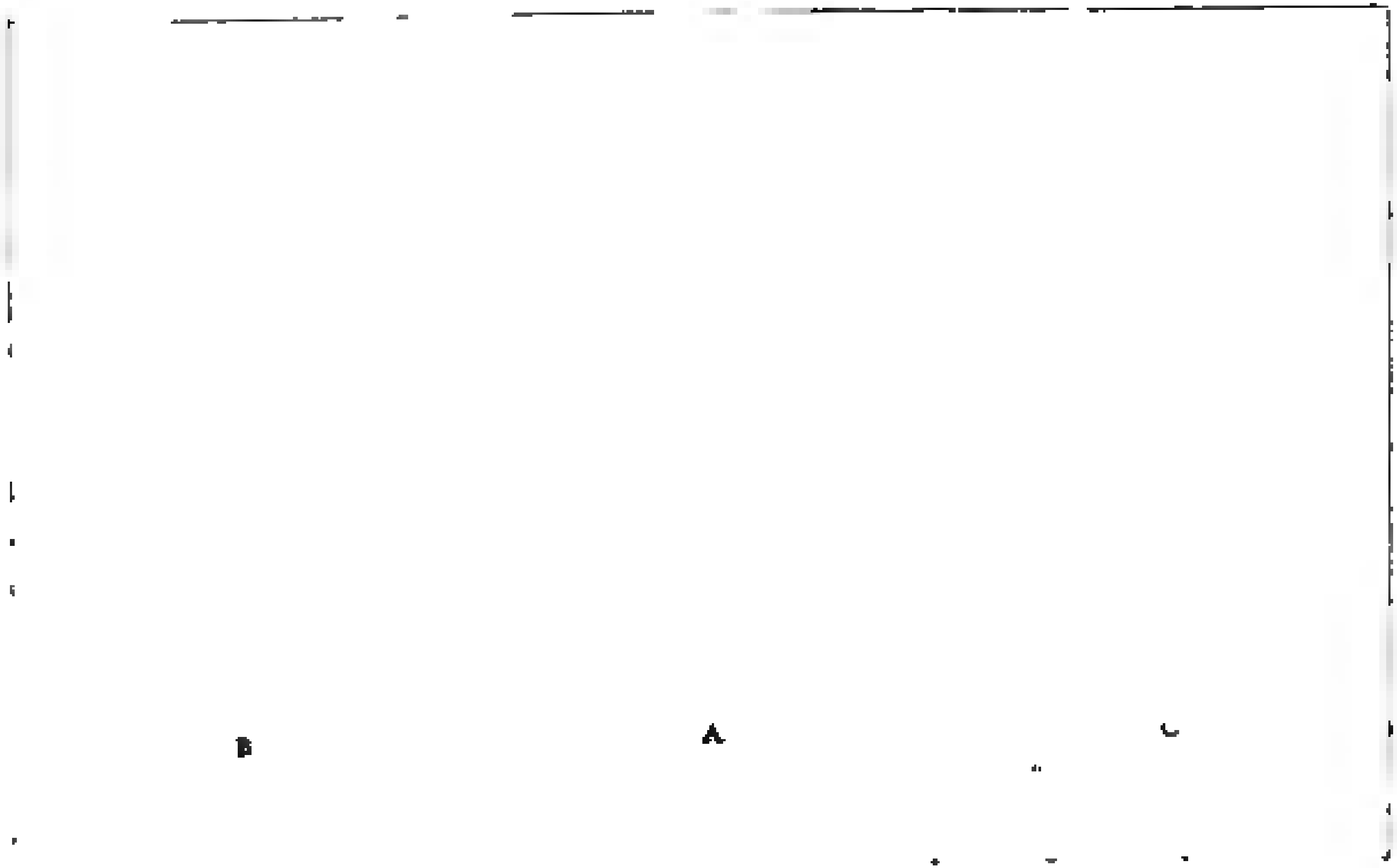

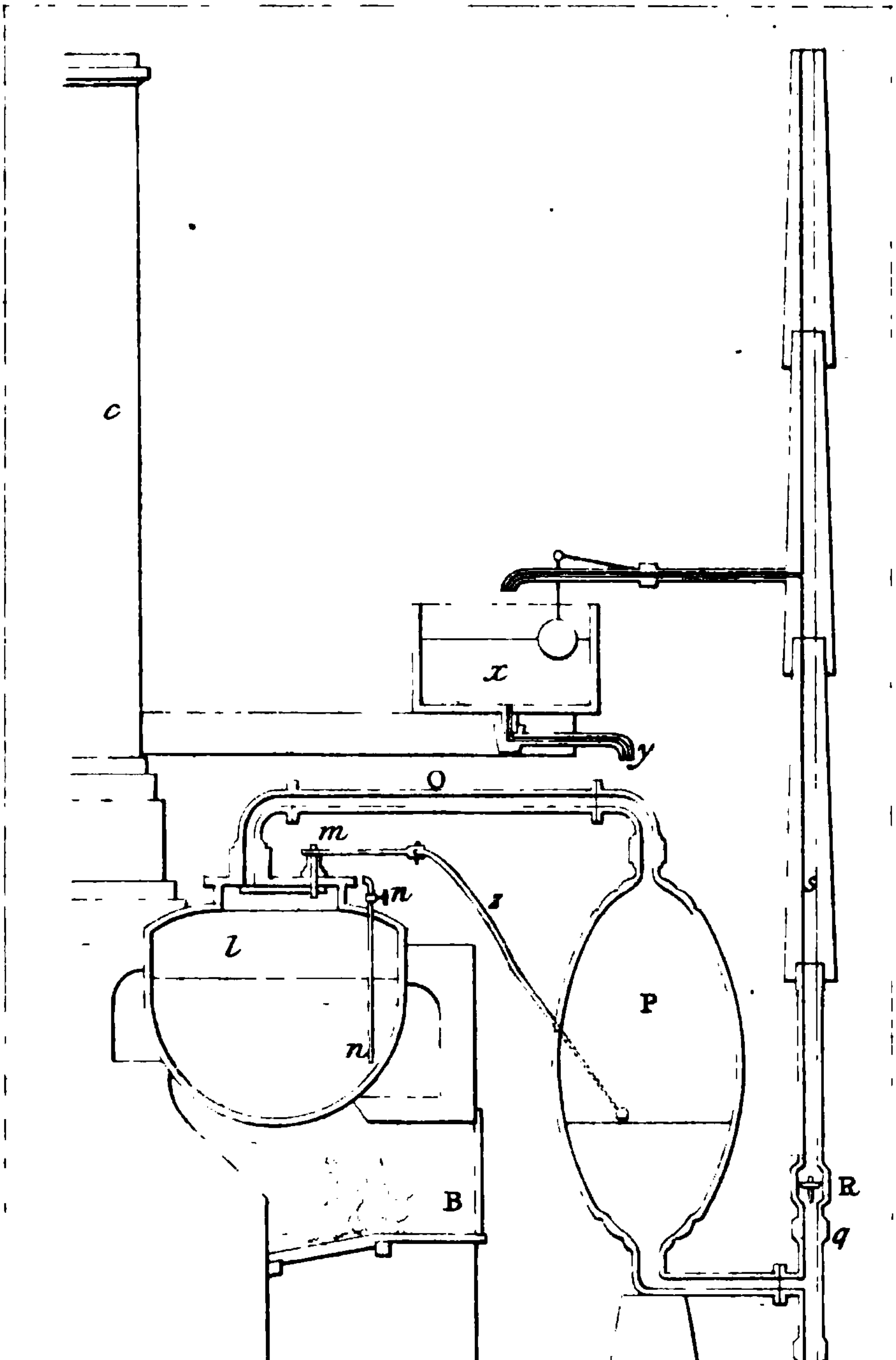
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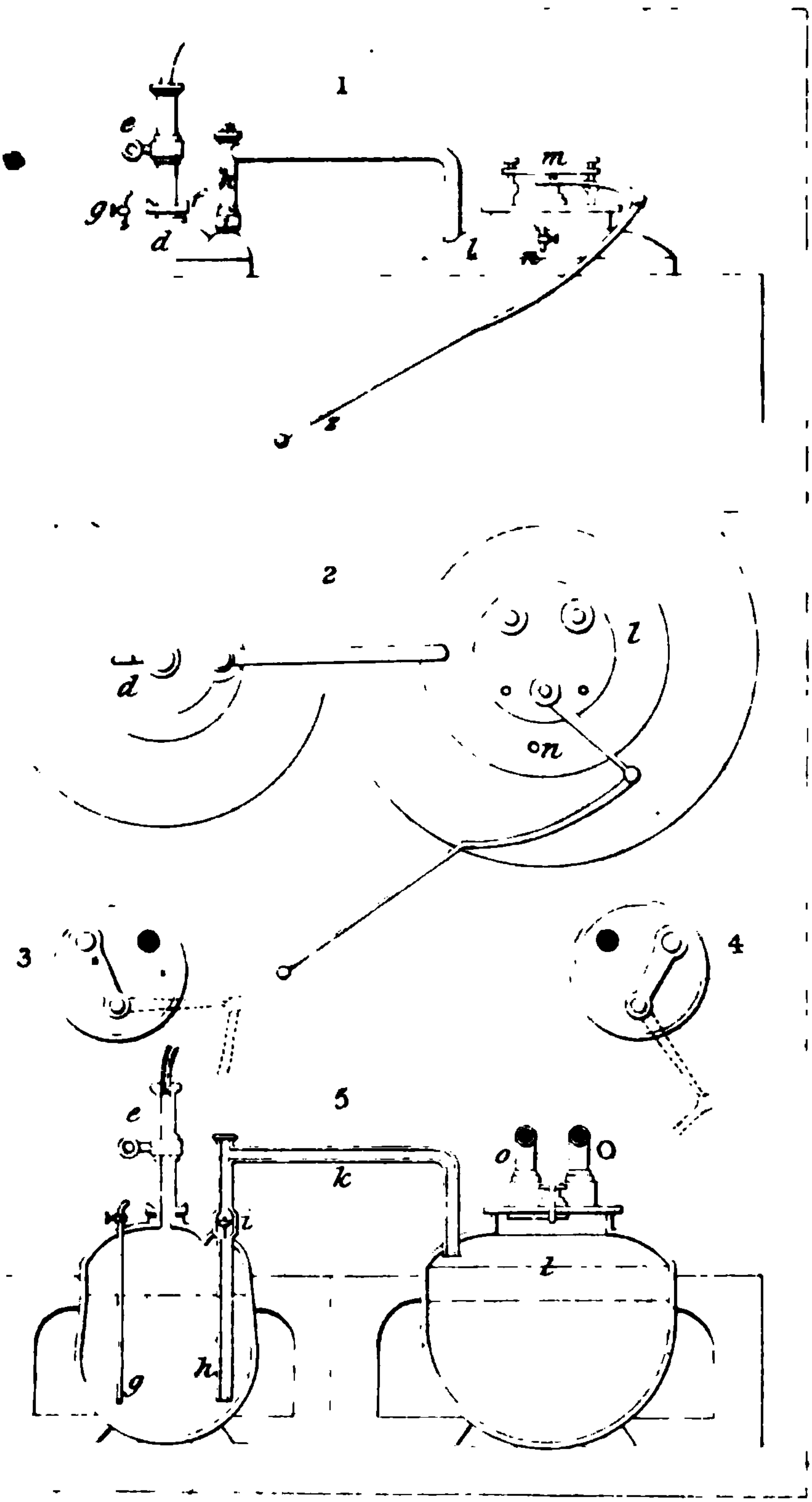
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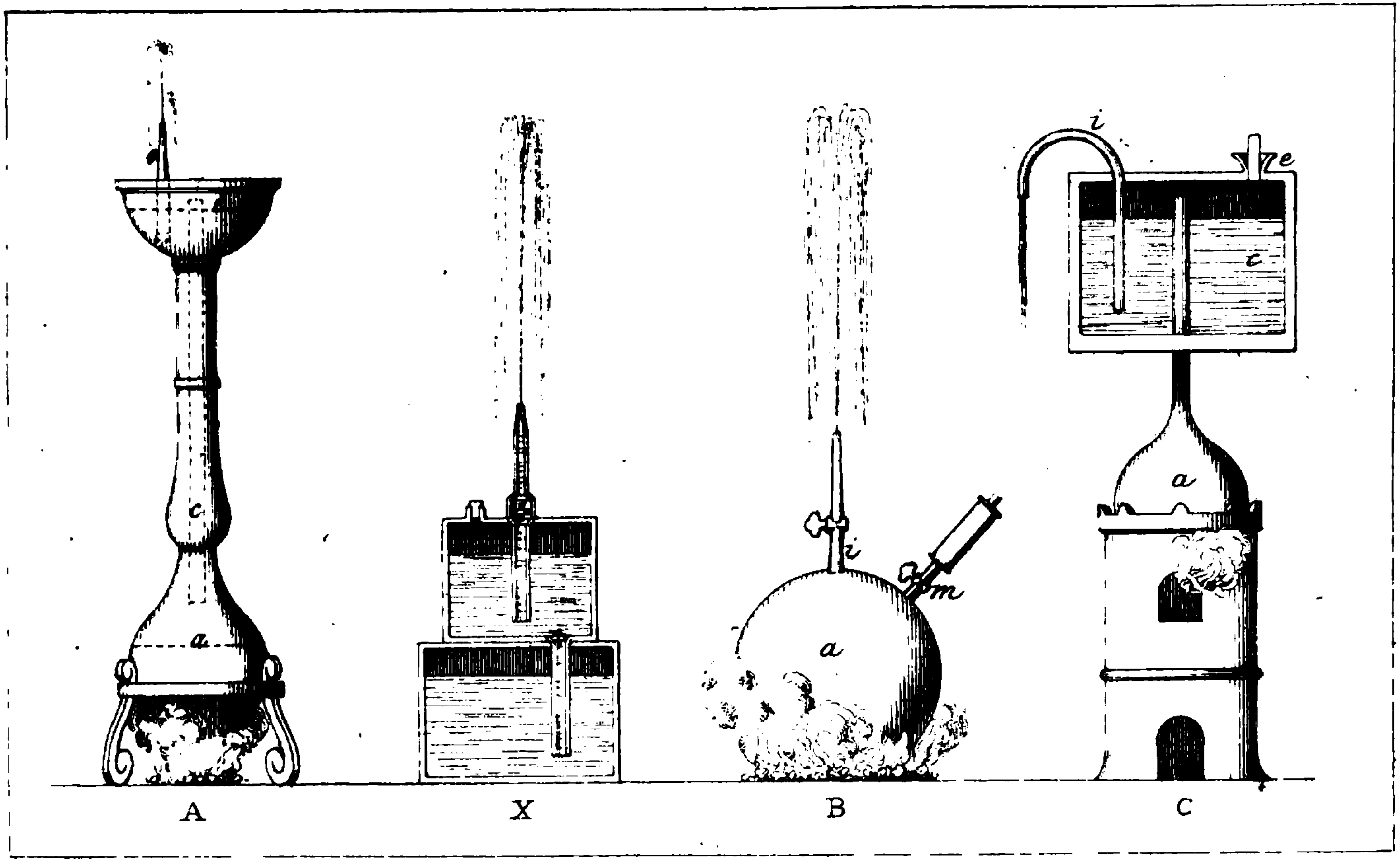
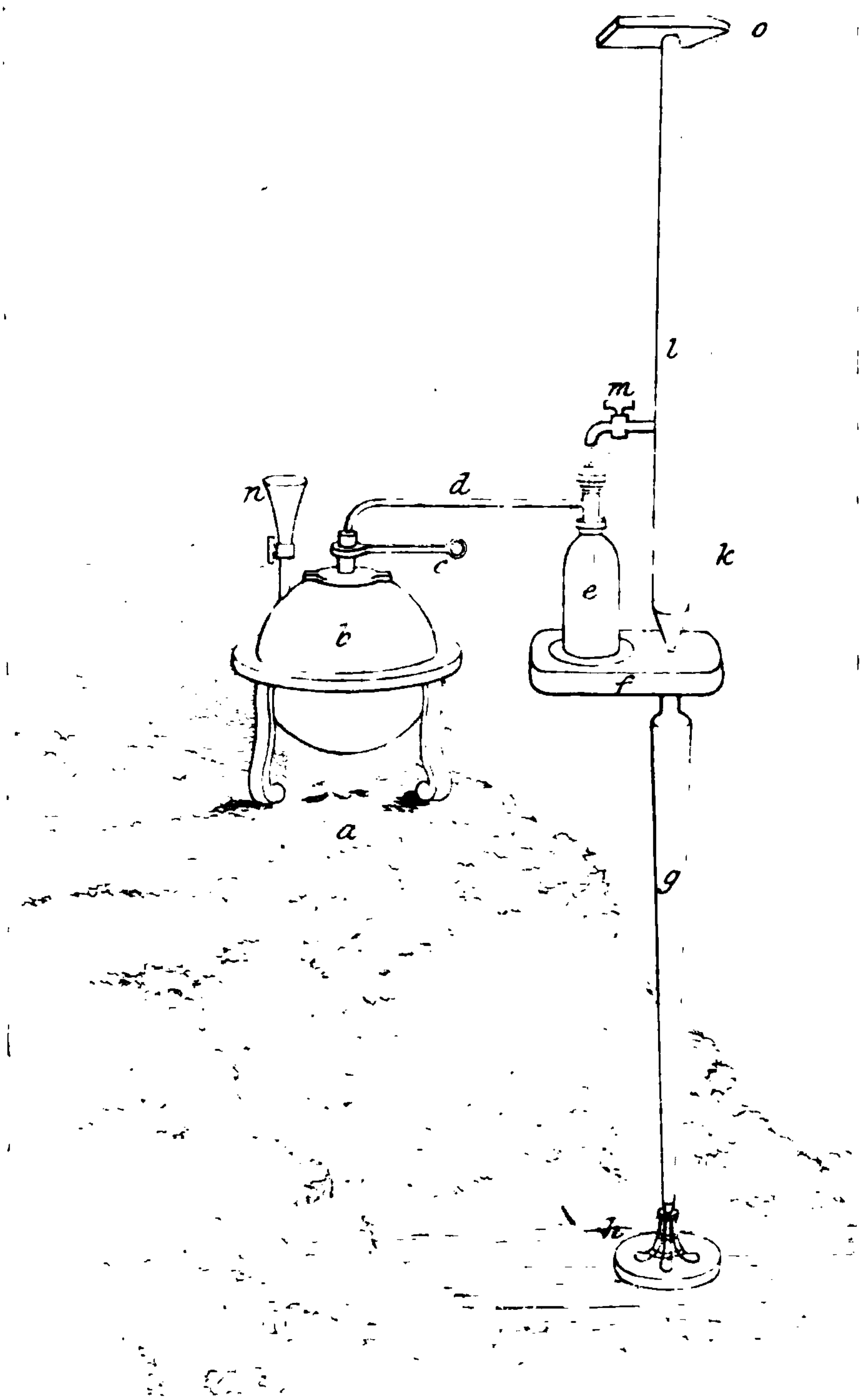


WORCESTER

BRANCA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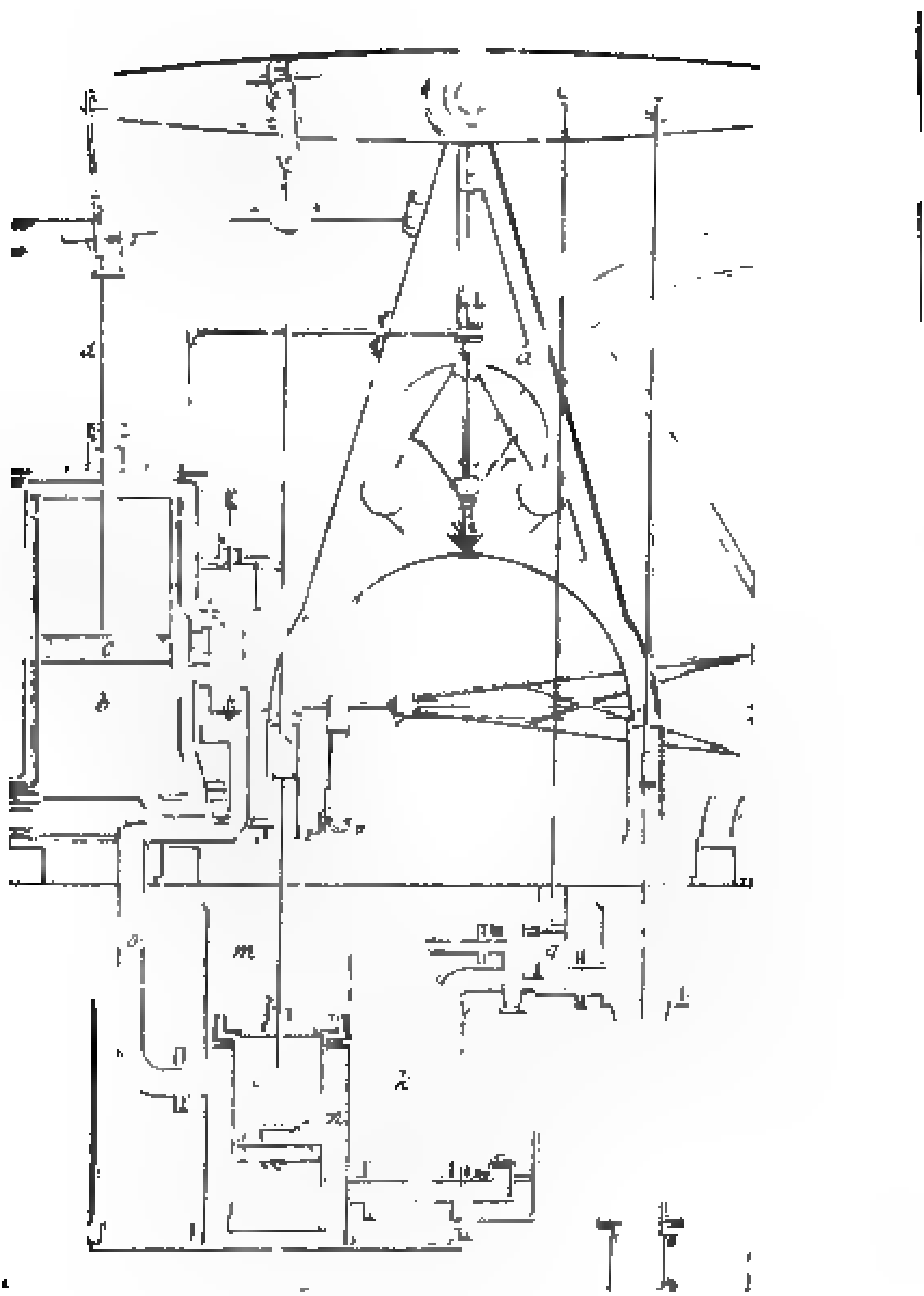

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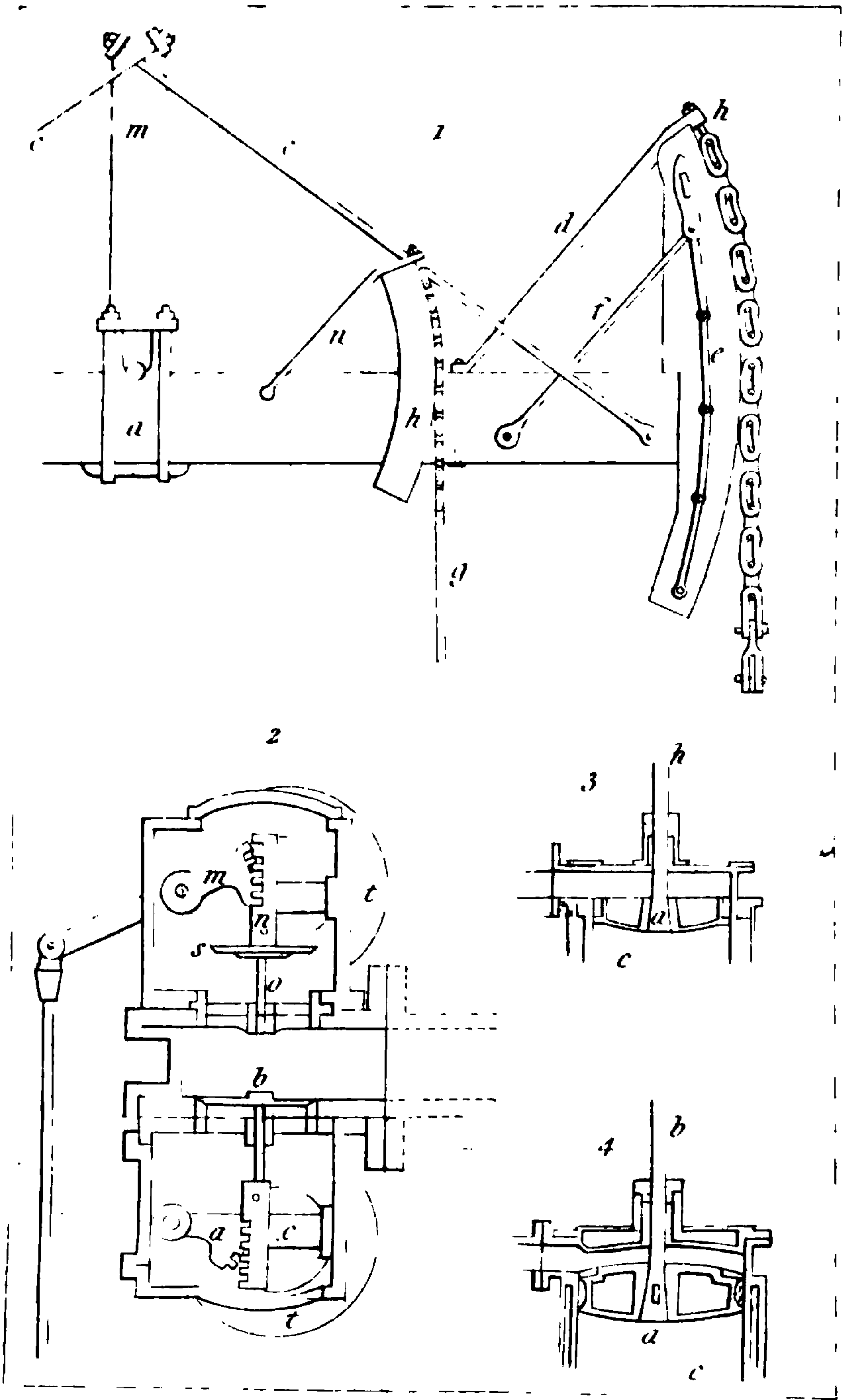
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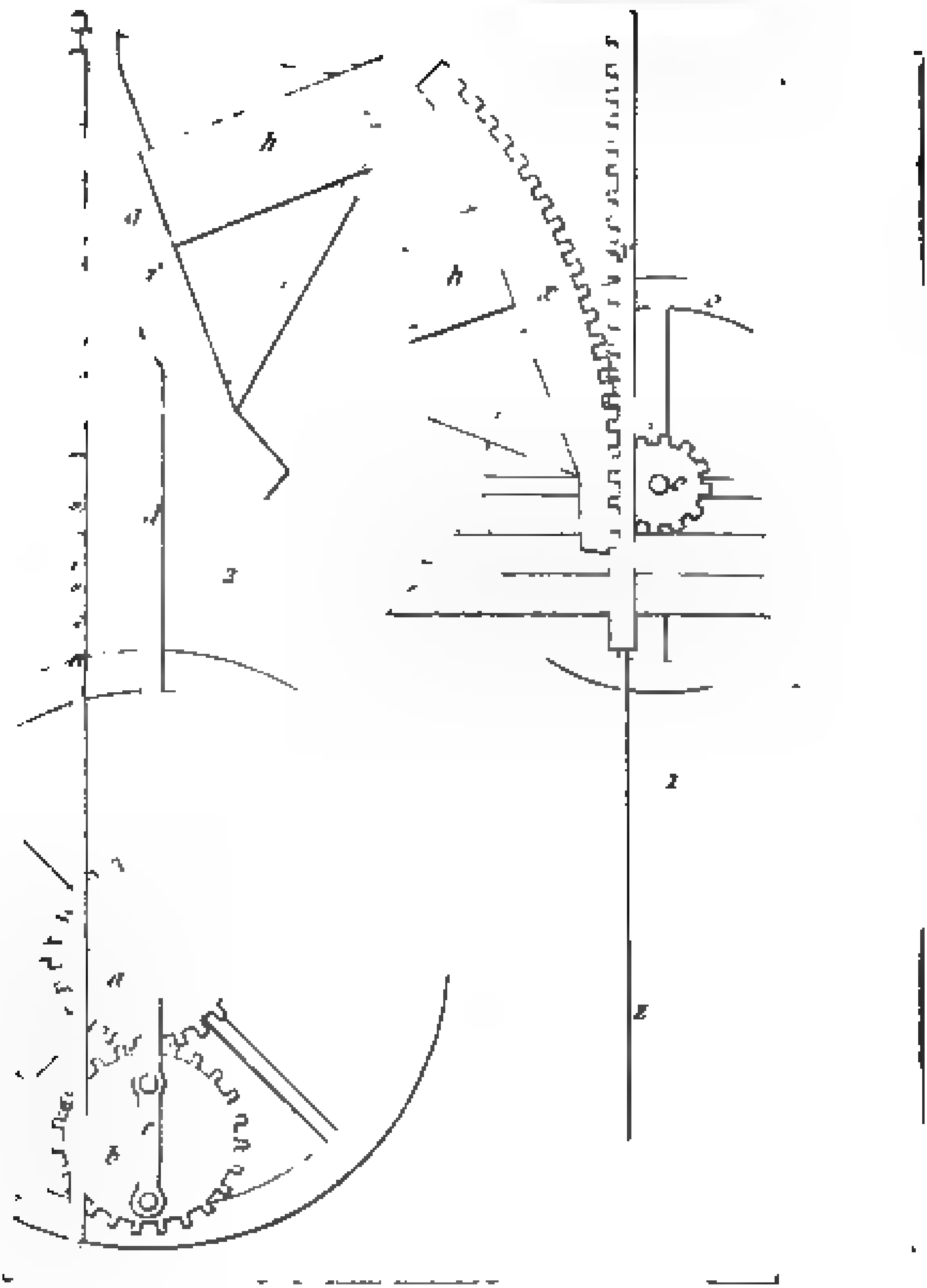

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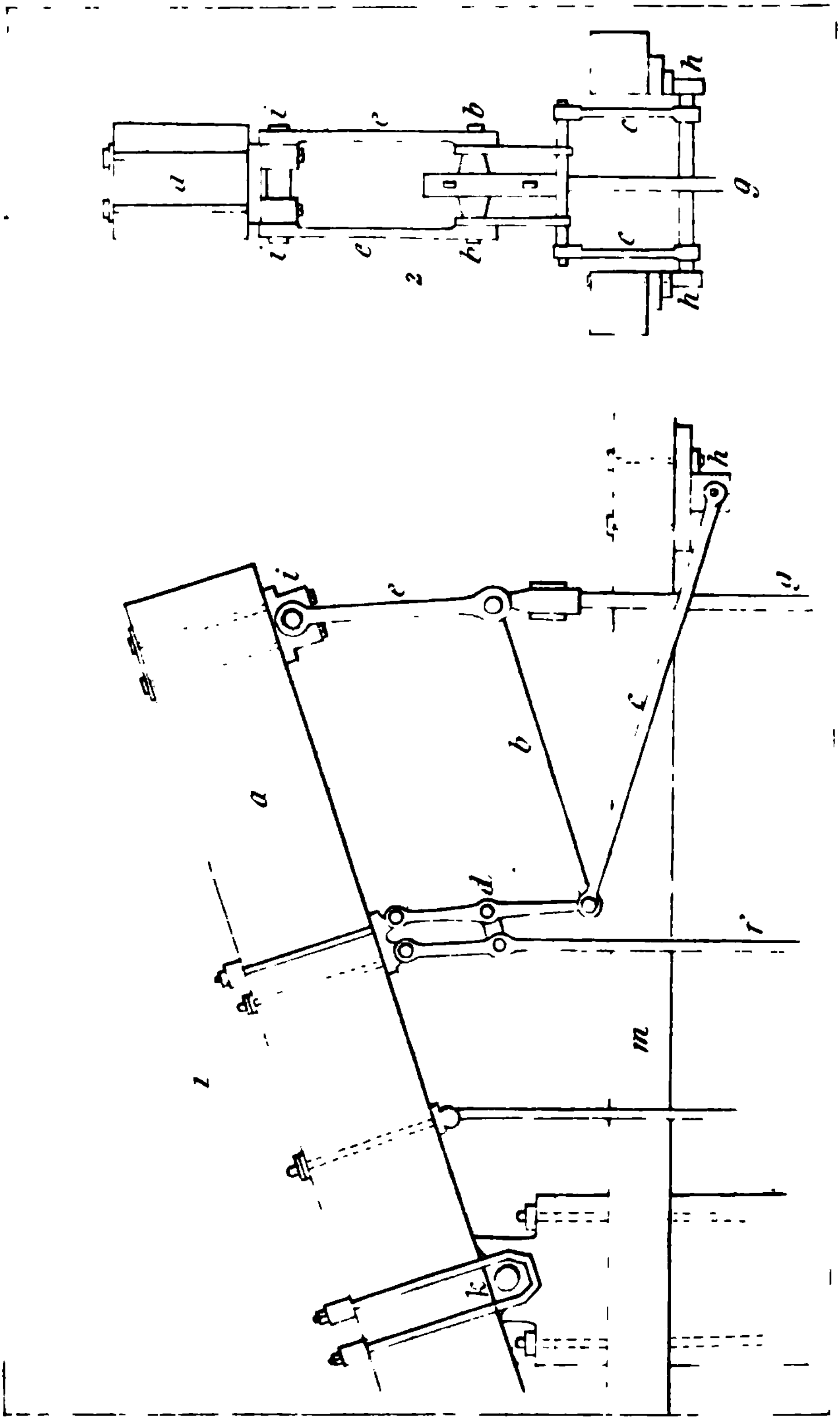

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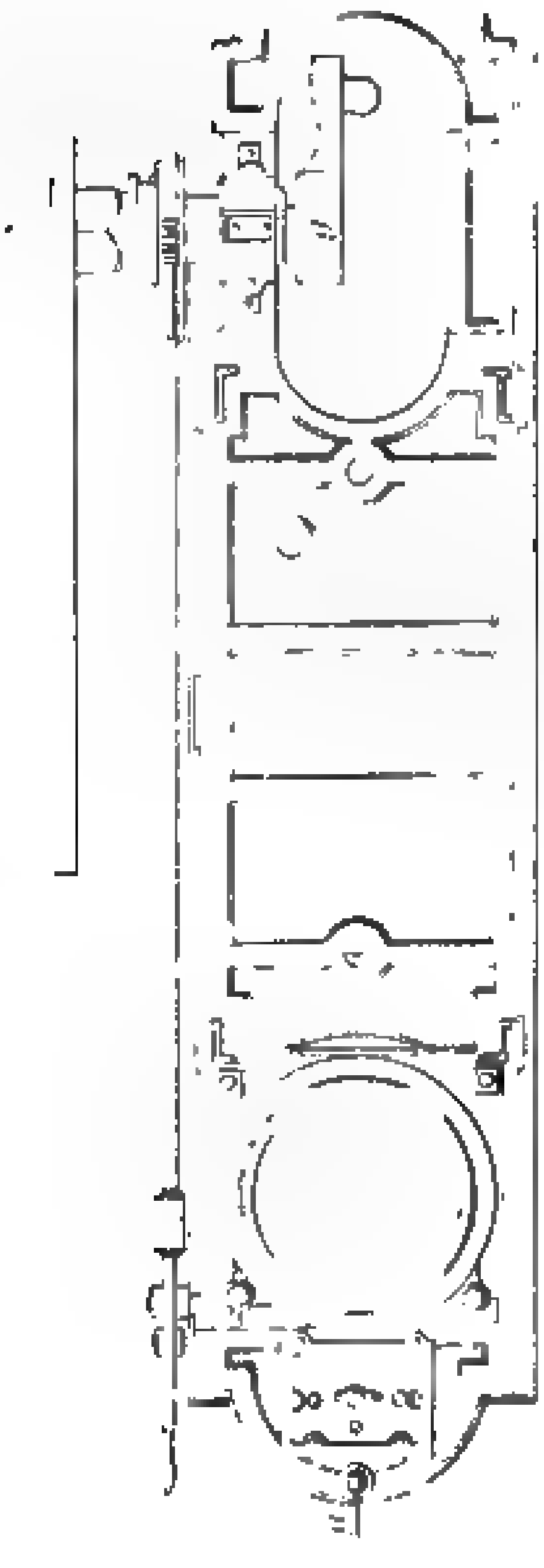

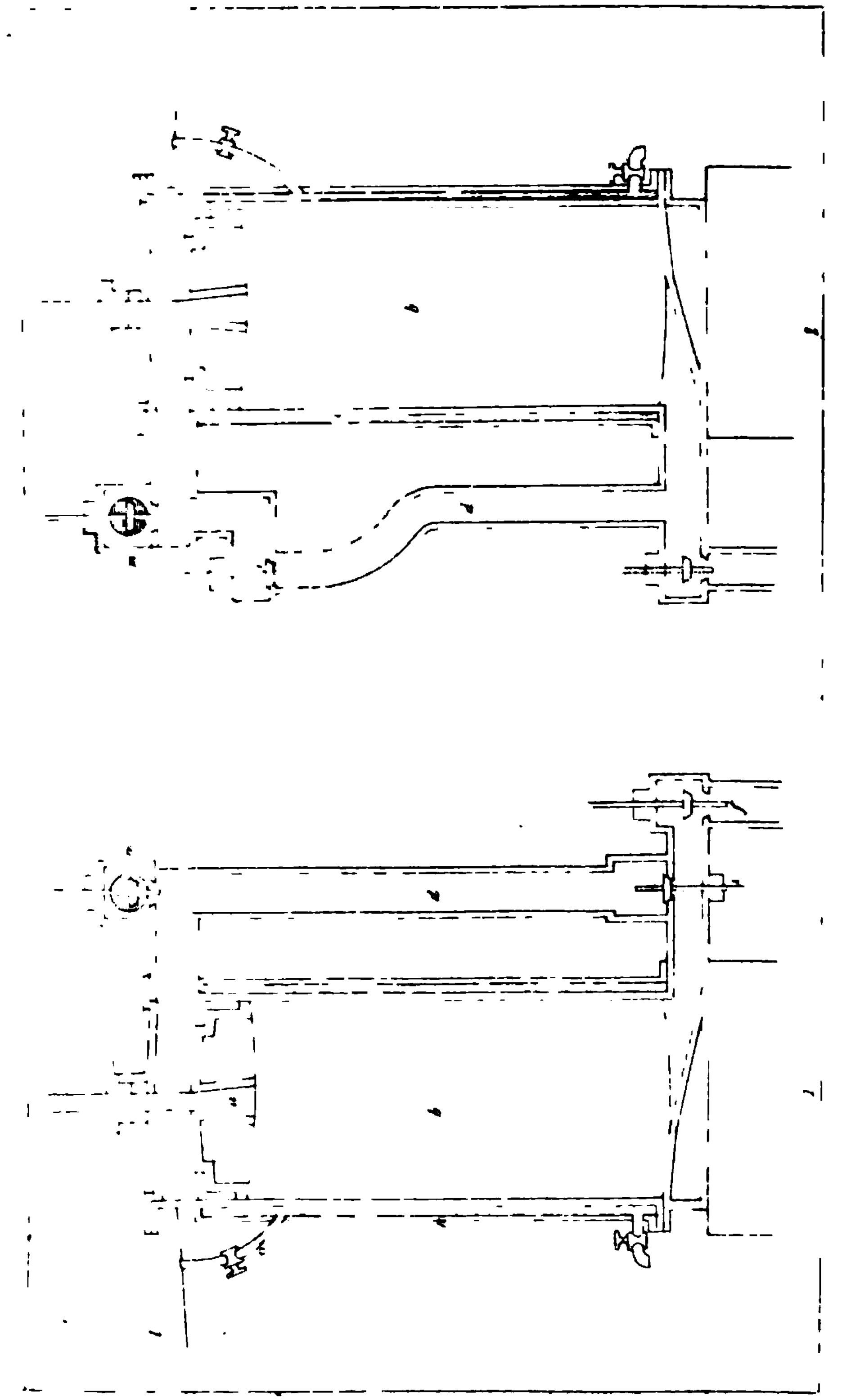

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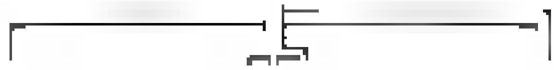

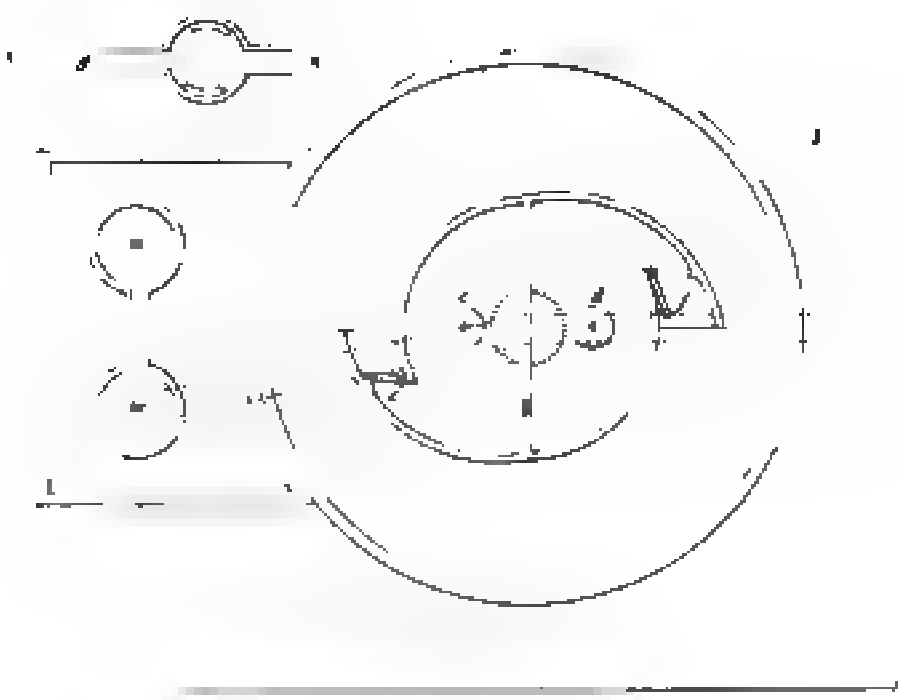

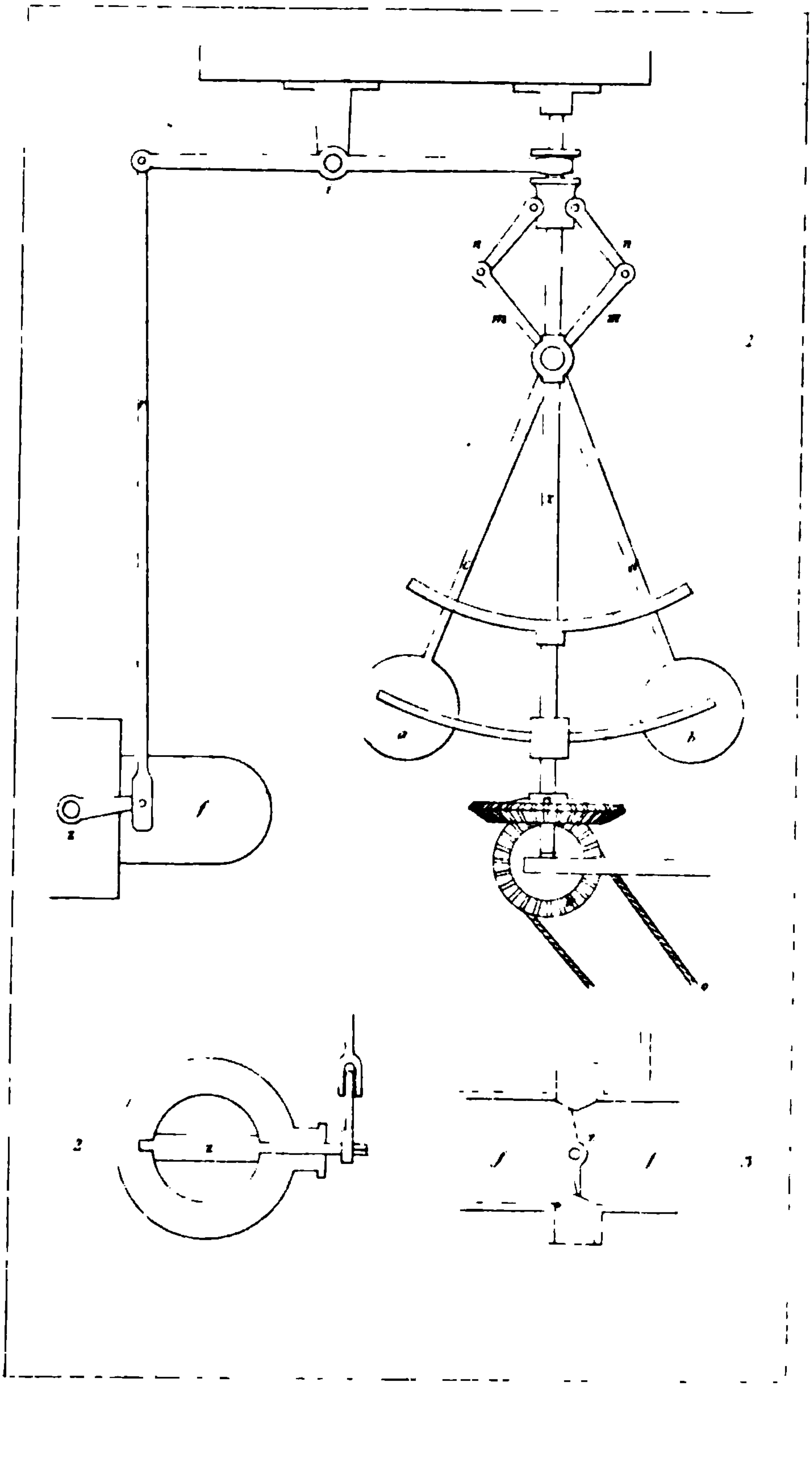

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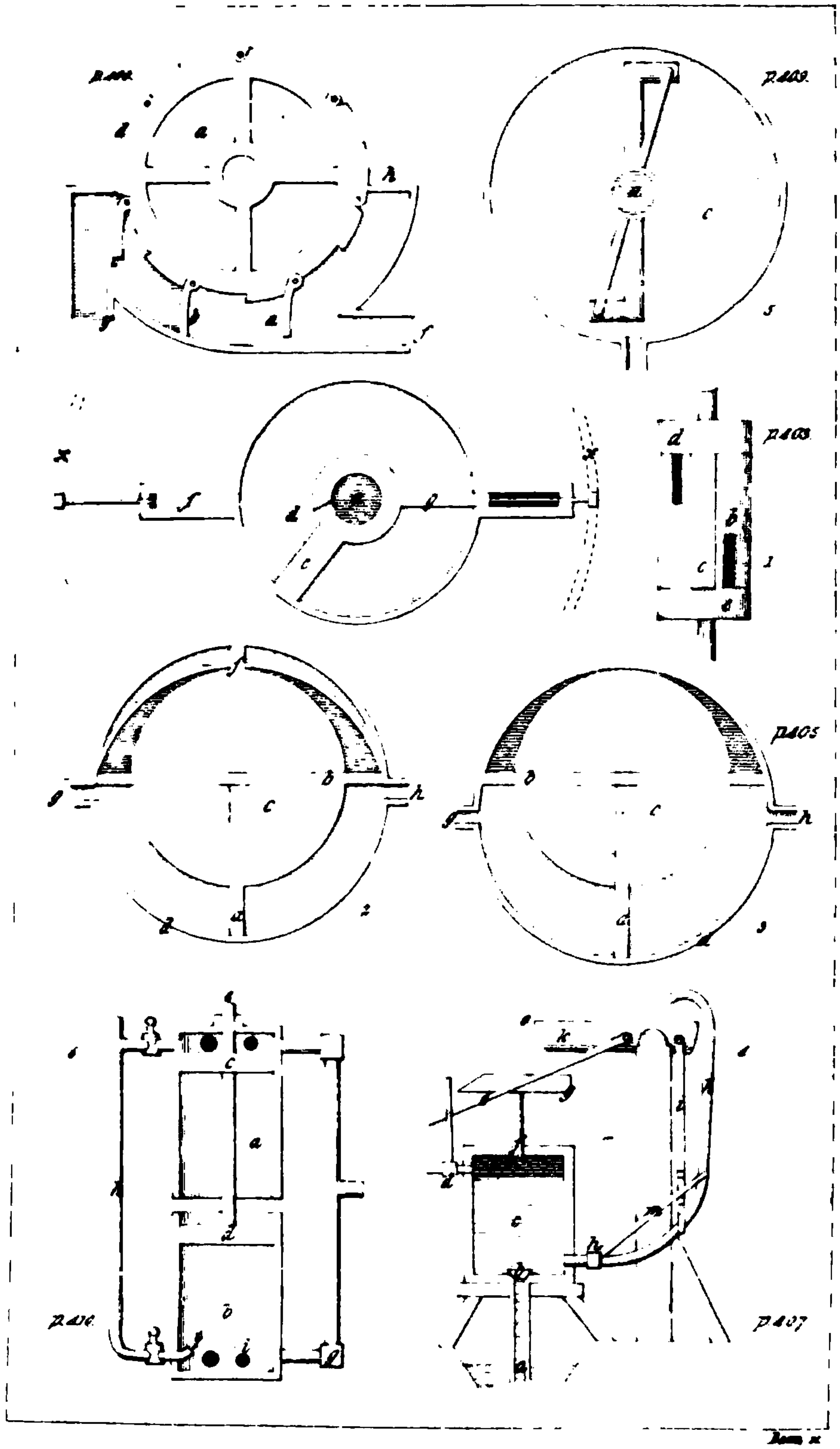

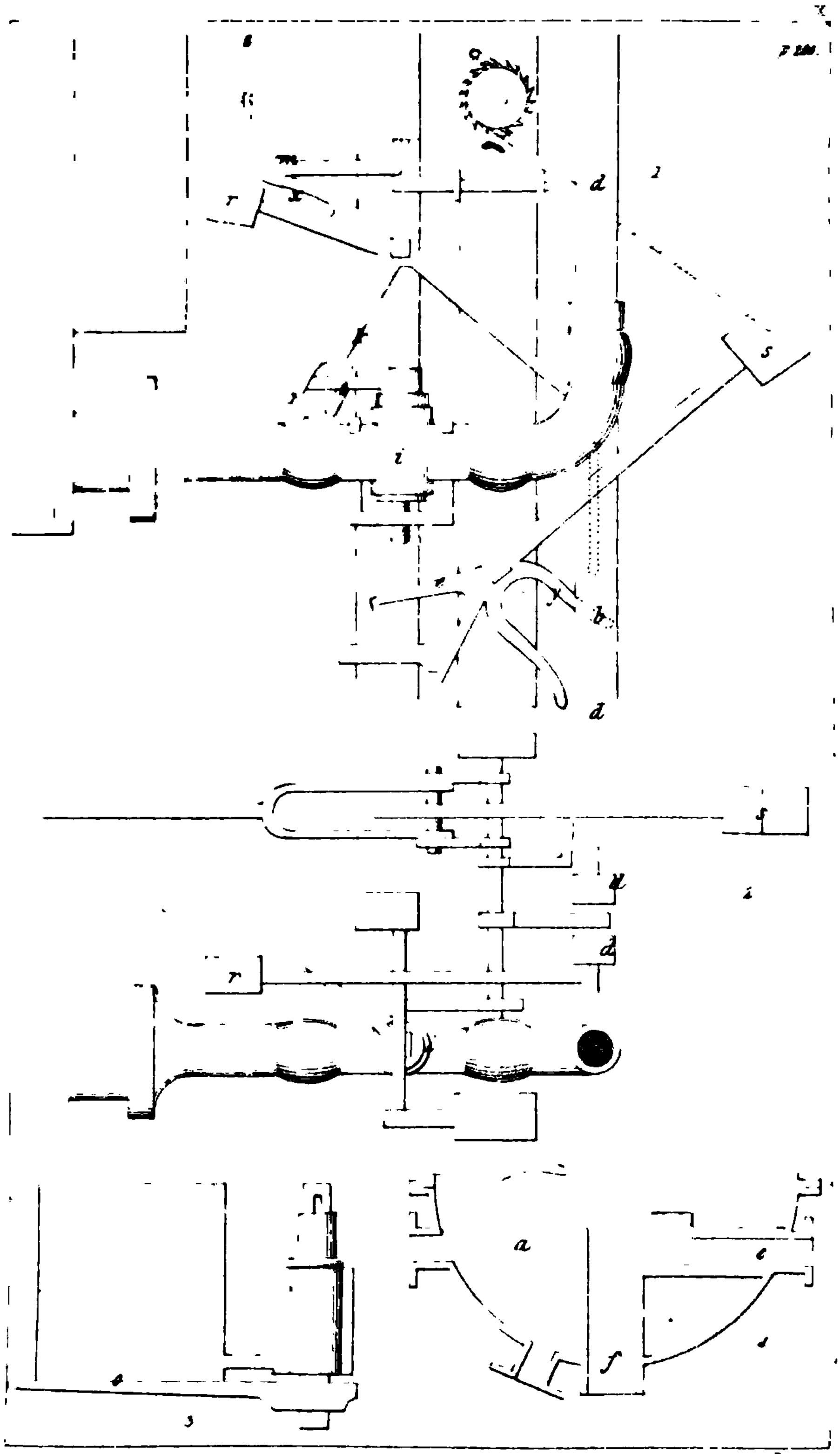
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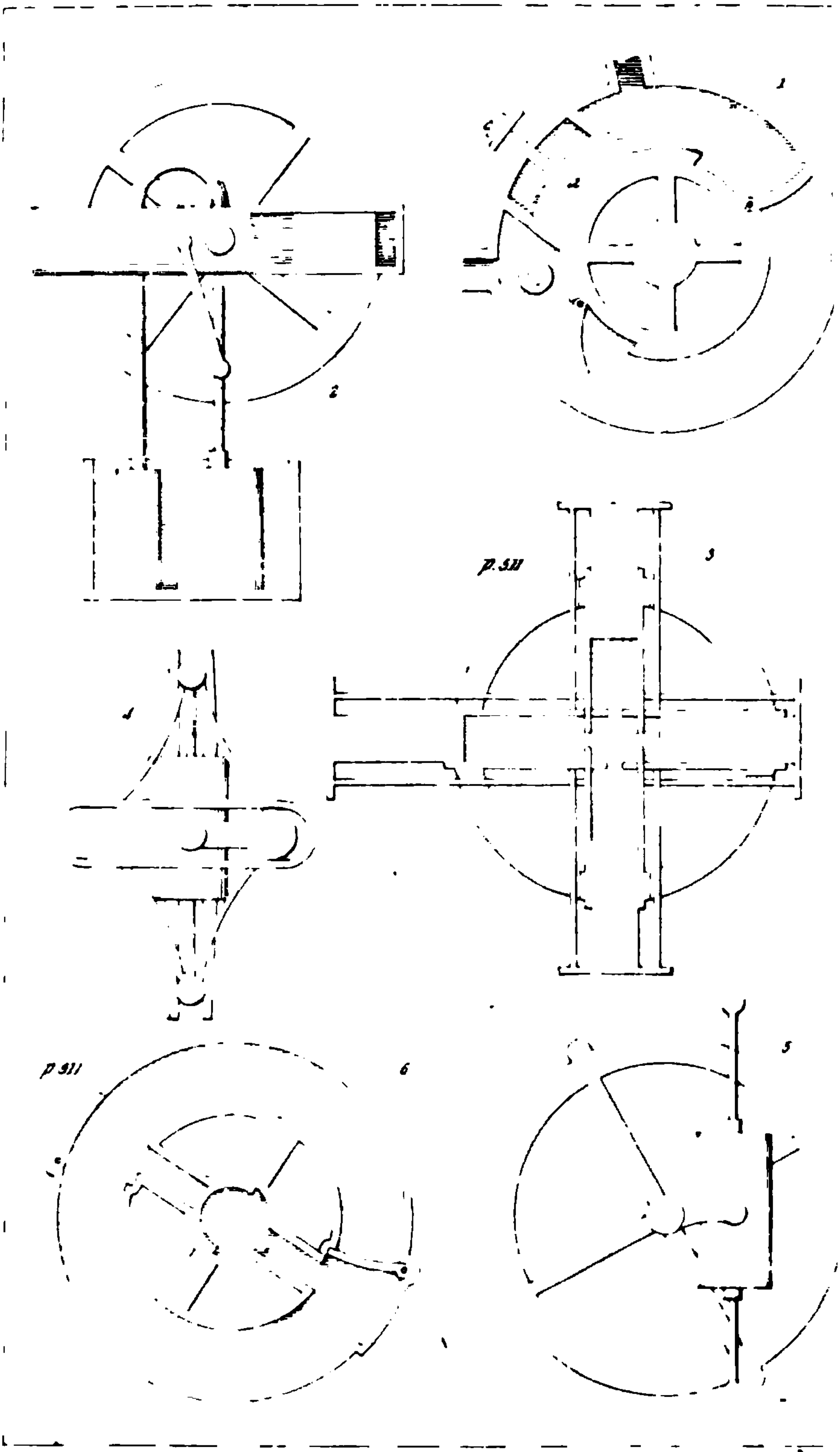

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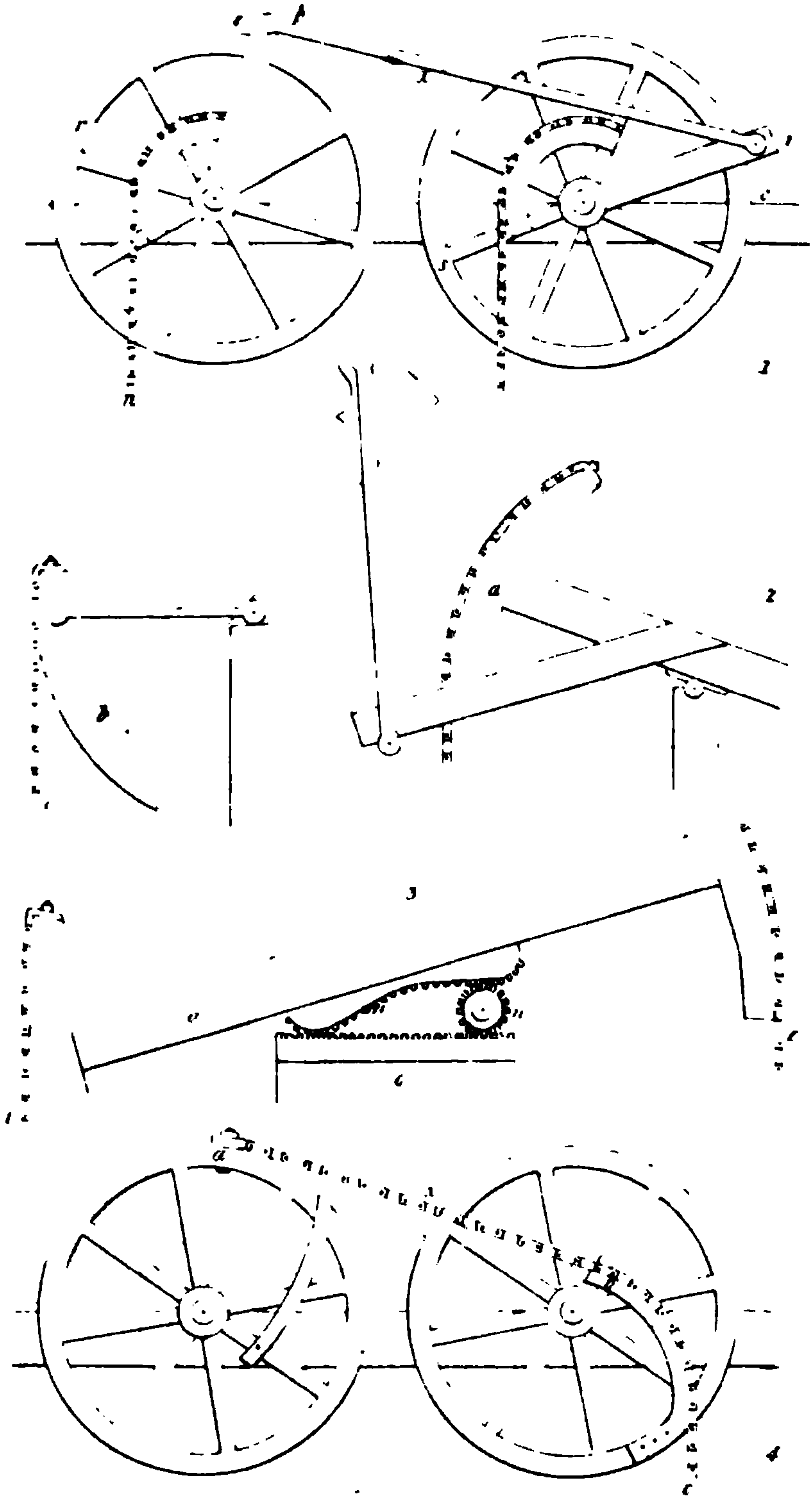

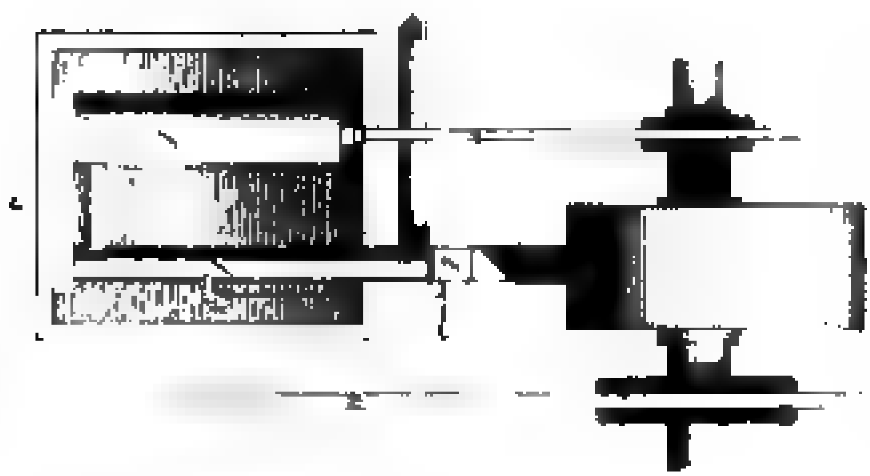

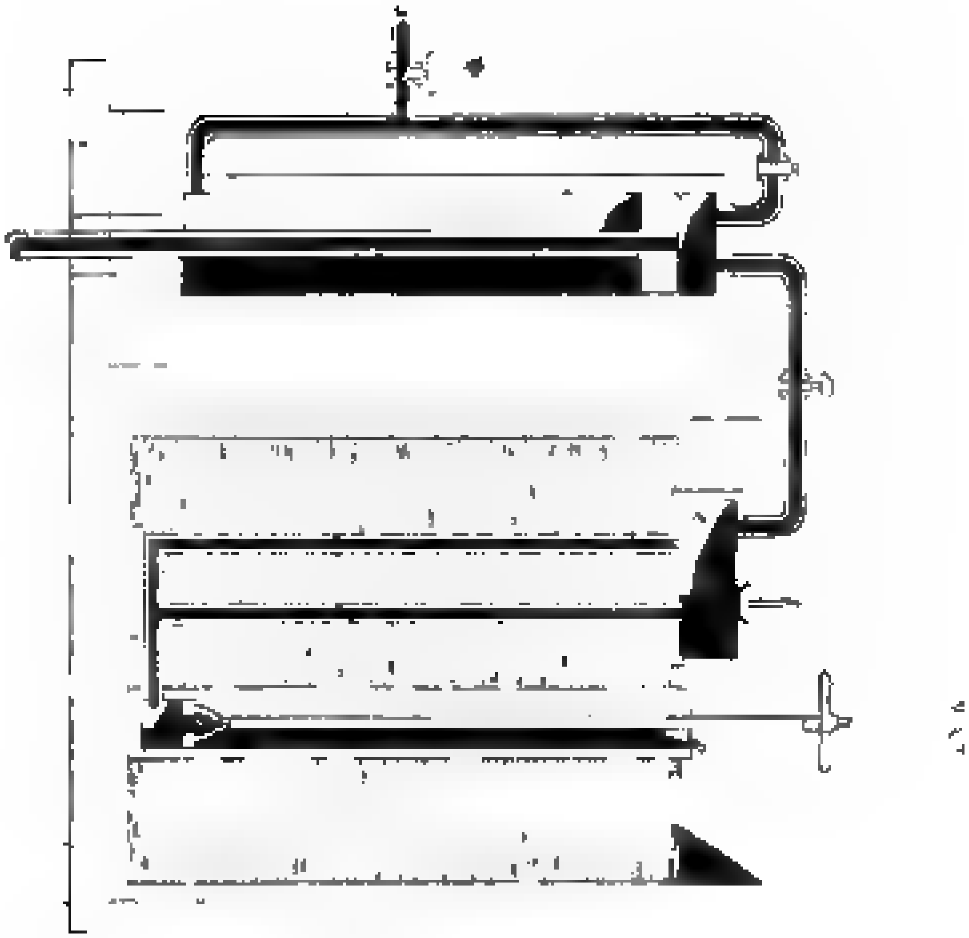

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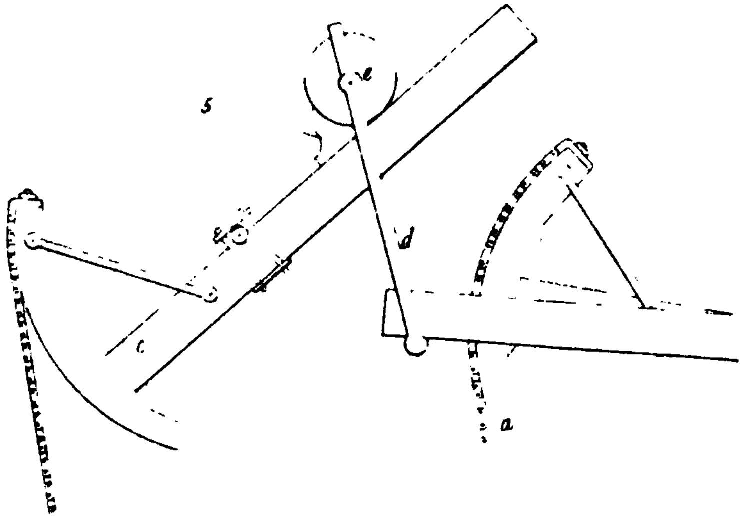

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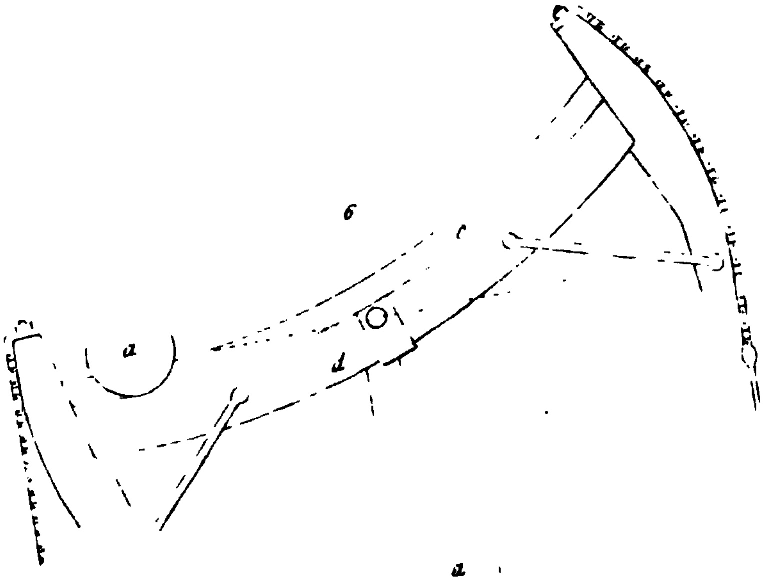

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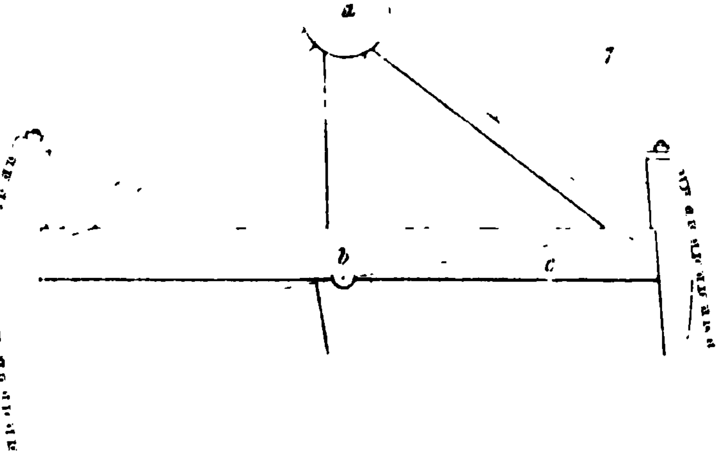

22